DETERMINING THE ORBIT LOCATIONS OF TURKISH AIRBORNE EARLY WARNING AND CONTROL AIRCRAFT OVER THE TURKISH AIR SPACE

THESIS

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Abstract

The technology improvement affects the military needs of individual countries. The new doctrine of defense for many countries emphasizes detecting threats as far away as you can from your homeland. Today, the military uses both ground RADAR and Airborne Early Warning and Control (AEW&C) Aircraft. AEW&C aircraft has become vital to detect low altitude threats that a ground RADAR cannot detect because of obstacles on the earth. Turkey has ordered four AEW&C aircraft for her air defense system because of the lack of complete coverage by ground RADAR.

This research provides optimal orbit locations that can be updated according to the threats, for Turkish AEW&C aircraft in the combat arena. Three combat scenarios Turkey might encounter are examined. Turkey can expect threats from everywhere. The worst cases for these scenarios include bad weather conditions and in Electronic Counter Measure (ECM) environment, adversary Surface to Air Missile (SAM) sites which are located in areas unknown to Turkish intelligence and no Suppression of Enemy Air Defense (SEAD) aircraft which can eliminate the SAM sites using High Speed Anti-Radiation Missiles (HARM).

The concern is to cover and detect the threats as far as possible from Turkey within a risk that the commander accepts. The goal is to help decision makers decide how many AEW aircraft are needed to obtain full coverage.

In order to provide optimum results, a Maximal Coverage Location Problem technique is used and the model is coded in MATLAB® 2008a.

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I would like to dedicate this thesis to my wife who helped me during my hard days and my daughter.

Acknowledgments

This research does not contain the official policy of the Turkish Government or Turkish Air Force about locating the orbits of AEW&C aircraft and deciding how many more AEW&C aircraft Turkey needs. All the worst and best cases and threat directions of the combat arena are chosen by me. The maps to show the results are only for demonstration, not for implementation. I am solely responsible for all the comments and critiques in this research.

I would like to express my appreciation to my thesis advisor, Dr. James T. Moore for taking the challenge of guiding me through this thesis effort. This thesis would not have been complete without his expert advice and unfailing patience. I would also like to thank my reader Dr. John O. Miller.

I want to thank the Turkish Air Force and the great Turkish nation for providing me this wonderful Master's program opportunity.

I would like to thank my parents for raising and supporting me all my life. Finally I would like to thank my wife. I could not complete this thesis without her help and support. My gratitude will be forever.

Nebi SARIKAYA

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DETERMINING THE ORBIT LOCATIONS OF TURKISH AIRBORNE EARLY WARNING AND CONTROL AIRCRAFT OVER THE TURKISH AIR SPACE

I. Introduction

1.1 Overview

This chapter presents information about Turkey and as a background, general information on air defense systems and its objectives, the Turkish air defense system, a brief history of the evolution of the Airborne Warning and Control System (AWACS), the project under which Turkey procured the AWACS and named as “Peace Eagle”, and a statement of the main problem and some assumptions and limitations of the problem. The final section of this chapter provides a summary of this chapter and preview of the thesis.

1.2 Information about Turkey

In this section, brief history, location and neighbors of Turkey are presented. Mustafa Kemal ATATURK’s saying, “Peace at home peace in the world”, is explained.

1.2.1 Brief History of Turkey

Turks established Anatolia in 1071, with the victory of Manzikert (Malazgirt) war when the emperor of the Great Seljuk Empire, Sultan Aplarslan, defeated the Byzantine army. After the weakening of the Anatolian Seljuk State, several beylics emerged in Anatolia. In 1299, Ottoman Beylic succeeded to unite the beylics (like states in Turkish) and founded the Ottoman Empire. In 1453 Fatih Sultan Mehmet II conquered Constantinople which is the former name of Istanbul. The Ottoman Empire lasted more

than six hundred years. At the beginning of the 20^{th} century, the Ottoman Empire weakened and during the 1^{st} World War (1914-1918), several countries including Greece, Great Britain, France and Italy captured most of the Ottoman lands of Anatolia. Mustafa Kemal ATATÜRK defeated the intruders in the Tukish War of Independece and founded The Republic of Turkey on 29 October 1923.

1.2.2 Location and Neighbors of Turkey

Turkey is located where the Asian, European and African continents are closest to each other. Turkey has a unique location, bridging the Asian and European continents. In other words she is located where the continents meet. The country has a roughly rectangular shape with a length of approximately 800 nautical miles (NM) and width of approximately 300 NM. Turkey is located in the northern hemisphere between $36^0 - 42^0$ northern parallels and the $26^0 - 45^0$ eastern meridians and has two European and six Asian neighbors. The Asian neighbors are Armenia, Azerbaijan, Georgia, Iran, Iraq and Syria, and the European neighbors are Bulgaria and Greece.

The total land border of Turkey is 1552 NM and total coast lines (including islands) are 4500 NM. The land border with each neighbor country is as follows: with Armenia 177 NM, with Azerbaijan 10 NM, with Georgia 149 NM, with Iran 284 NM, with Iraq 204 NM, with Syria 473 NM, with Greece 110 NM, with Bulgaria 145 NM.

Throughout history, the mainland of Anatolia has always found favor, because of the strategic importance of its location. Anatolia is the birth place of many civilizations. The mixture of cultures still shows itself in Turkey. It has also been prominent as a center

of commerce because of its land connections to three continents and seas surrounding it on three sides (Embassy of the Republic of Turkey).

Figure 1. Map of Turkey and Neighbors (www.wikipedia.org)

1.2.3 "Peace at Home, Peace in the World

Mustafa Kemal ATATÜRK who is the founder of the Republic of Turkey took great effort to keep the peace among the countries who are the neighbors of Turkey until he went away to other the world on 10 November 1938. He wanted the whole world to be in peace and he emphasized the belief of Turks to the World by saying "Peace at Home Peace in The World". Turkey's first goal is to keep the peace in its region. But as everyone can see, there are some countries which are improving their armed forces with nuclear weapons and other technologic weapons. Turkey has to defend the country in case of an attack. Turkey does not have any intention to attack any country; she wants to live in peace with other countries.

1.3 Background

1.3.1 Air Defense

The era of air defense was opened by the first use of balloons in France in 1783. The balloons were used by French to observe enemy lines. On the other hand Austria attempted to prevent the French balloons by shooting at them. This was the first active air defense in history (Crabtree, 1994). After the invention of the aircraft by the Wright Brothers in 1903, military experts wanted to improve and use the aircraft as an attack weapon against enemies. Especially, Germany produced and used lots of aircraft during the 1st World War against Great Britain. On the other hand, Great Britain invented Radio Detection and Ranging (RADAR). Countries began to use RADAR, and they improved it by making technological advances. But ground RADARs could not adequately satisfy low altitude coverage, since the surface of the earth is not plane. Military experts and operations researchers tried to locate RADARs on the high mountains, optimally. Along with the advance of RADAR, engineers and technicians improved the detection and lethal ranges of Surface to Air Missile (SAM) systems and fighter aircraft. Airbirne Early Warning (AEW) aircraft became vital for air defense. This aircraft can detect threats far enough from targets to alert the air defense components without entering the threats' lethal ranges. In an air defense context, the problem is to detect the incoming raiders in sufficient time and to launch the defending fighters to destroy them before they reach their targets (Elsam, 1989).

Today, fighter aircraft, AEW aircraft, ground RADAR, SAM and short range air defense (SHORAD) systems and Command, Control, Communications, Computers,

Intelligence and Reconnaissance (C4ISR) systems constitute the components of air defense as a combination. The information is transmitted rapidly by data links between the components.

1.3.2 Turkish Air Defense System

The Turkish Air Forces' (TUAF) mission to defend its homeland against threats included defense of the air by fighter aircrafts. But because of the latest technological developments in long range tactical and ballistic missiles and new generation aircraft, TUAF has changed its defensive approach. Turkey's early warning system is based on only ground RADARs. Because of the lack of adequate coverage by this early warning system, Turkey wants to minimize the coverage short fall by initially ordering four Airborne Early Warning and Control (AEW&C) aircraft, with plans to order others as needed.

Because of the strategic importance of the location of Turkey, she needs to defend herself with a strong military which can detect and identify the attackers early enough to get ready to react. Neighbors of Turkey are continuing to produce or procure new offensive weapon systems like ballistic missiles and new generation fighter aircrafts. Iran is suspected of developing nuclear weapons. On the other hand Turkey and Greece have had conflicts over Aegean Sea and airspace since 1954. Greece has a tendency to use her weapons in the Aegean region, although she is a member of NATO. She locates airbases and missile defense systems on Aegean islands which are not supposed to house military personnel and weapon systems according to the Treaty of Lausanne, 1923.

Turkey is planning to procure not only AEW&C aircraft, but also 100 F-35A "CTOL/Air Force versions" and long range surface to air missile defense system and she is modernizing F-16 aircraft. Turkey's defense industry is growing more and more. ASELSAN and HAVELSAN are major Turkish companies which produce defense systems and also export these systems to other countries. HAVELSAN is participating in the acquisition of Peace Eagle AEW&C as the sole in-country subcontractor of BOEING for the Mission Computing Segment (MCS) and Ground Support Segment (GSS).

Air defense systems can be strong enough to repel invaders only with AEW aircraft. Initially, Turkey ordered four AEW aircraft with other options to include six, seven or eight aircraft. Turkey has to decide how many more AEW&C aircraft are needed. This research does not reflect the official policy of the TUAF or Turkish Government.

1.3.3 Development of Airborne Early Warning (AEW) Aircraft

AEW aircraft changed the nature of warfare. These platforms give their commanders early warning and information on approaching aircraft and ships that previously was not available (Armistead, E.Leigh, 2002). AEW aircraft extended the combat arena and allowed commanders to have more time to plan their operations. The U.S. Navy had the lead in the development of AEW aircraft. Low-flying Japanese aircraft attacks in World War II revealed the need for a platform which can detect these aircraft early. Because of the curvature and roughness of the earth, ground RADARs could only detect low altitude flying fighter aircraft and other low level objects for a limited range. In order to identify the Japanese aircraft by visual detection, early reconnaissance methods involving patrol

and scout aircraft were tried, but these attempts often failed. AEW aircraft could theoretically detect an aircraft or ship at distances far superior to earlier systems and were viewed as the answer to this complex problem (Armistead, E.Leigh, 2002). It took over 20 years to develop a dedicated all-weather AEW aircraft since there were some severe technological problems. Research and development completed from 1942 to 1964 by the U.S. Navy was essential to the successful completion of a true AEW platform.

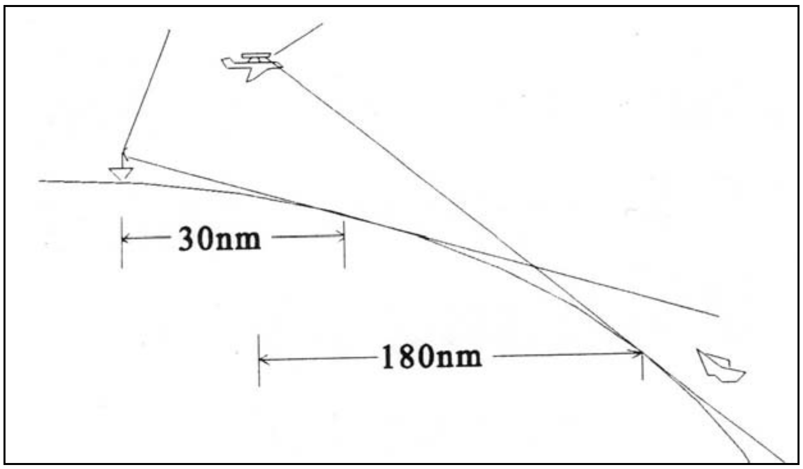
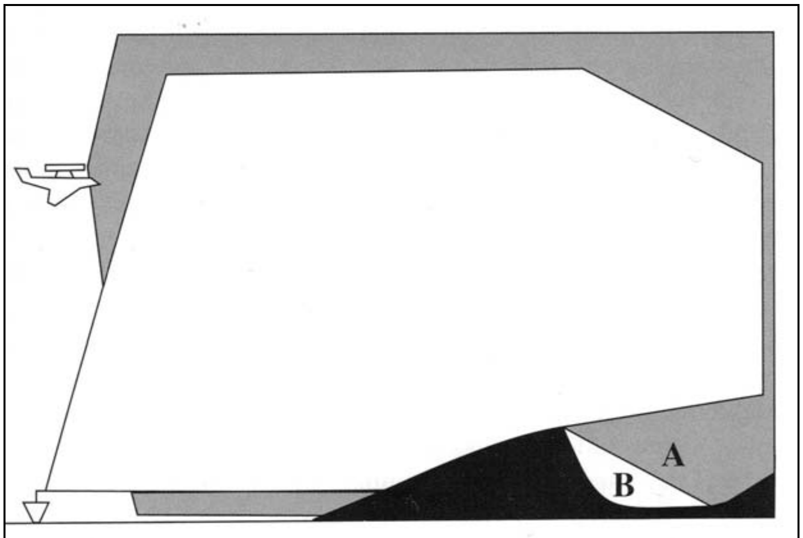


Figure 2. Line of Sight Constraints for Surface-Based RADAR systems (AWACS AND HAWKEYES 2002)

The 1960s were when the AEW first reached its potential. The E-2A and then E-2B were introduced. E-2C Hawkeye was first introduced in 1971 and it was the premier AEW aircraft in the world. A complete airborne command and control platform would never be fully realized on Hawkeye's airframe. EC-121Ds were modified for evaluating certain avionics for future use on the next-generation platform, the Airborne Warning and Control System (AWACS). The AWACS solved the seemingly insurmountable "ground clutter" problem of overland detection of aircraft by employing a pulse Doppler RADAR that could distinguish between flying aircraft and the ground below (Armistead, E.Leigh,

2002). The EC-121 system ultimately enabled weapons controllers to employ for the first time an airborne radar system in a command and control role. Official production of the AWACS program began on 26 January 1973, and Boeing E-3A was officially designated as the “Sentry”. With the arrival of the E-3A, the U.S. Air Force finally had a true over-the-horizon AEW aircraft that could track aircraft over land in a variety of terrain. (Armistead, E.Leigh, 2002). E-3A is a modified Boeing 707-320C and is still in operation in NATO. Other versions of the E-3 have been produced since the E-3A’s introduction.



A - Contacts are seem by AEW aircraft only
B - Contacts are not detected

Figure 3. Expanded RADAR Coverage with AEW Aircraft (AWACS AND HAWKEYES 2002)

While the advances on AEW aircraft were proceeding in the U.S. Air Forces, other countries’ air forces produced AEW aircrafts. First Soviet AEW aircraft was TU-114 in 1957. The A-50 “Mainstay” and IL-76 “Candid” are currently being operated by the Russian Air Forces. British Royal Air Forces used U.S. produced AEW aircraft until the first AEW aircraft, the Shackleton AEW2, was introduced in 1973. The E-3 Sentry is

currently being operated by British Royal Air Forces. Figure 4 shows the evolution of the AEW aircraft as a time line, according to the information from the book AWACS AND HAWKEYES, 2002. Currently a new Boeing 737 AEW&C aircraft project is on going. Japanese Air Self-Defense Forces bought new Boeing 767 AEW&C aircraft. As a result, most countries have realized the importance of the AEW aircraft.

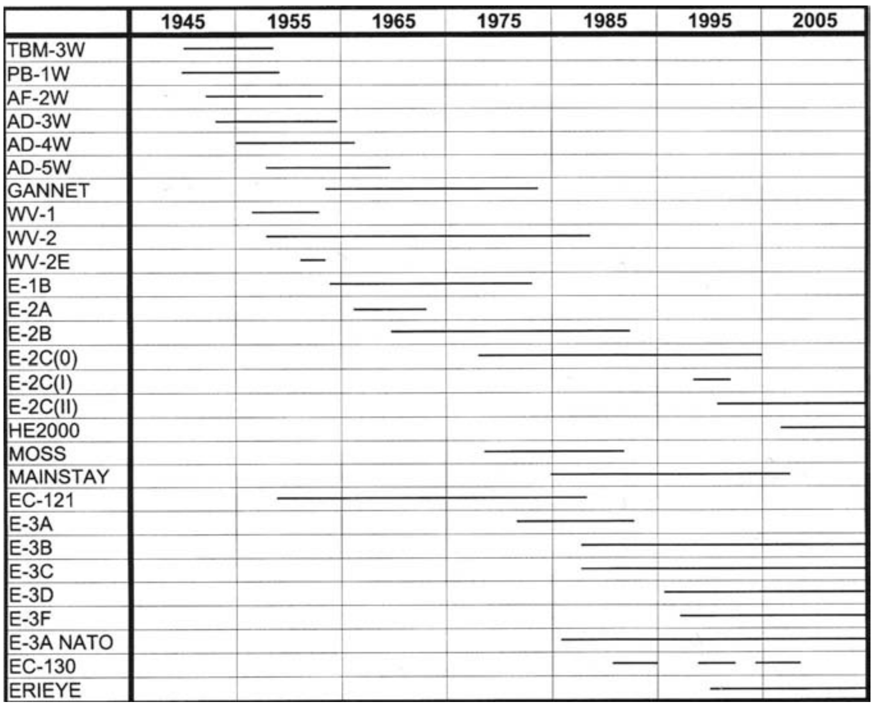


Figure 4. Evolution of AEW Aircraft: A Time line (AWACS AND HAWKEYES, 2002)

1.3.4 Project "Peace Eagle"

The Boeing Company is supplying the Turkish Air Force with an Airborne Early Warning and Control (AEW&C) system, known as Peace Eagle, based on the Boeing 737 AEW&C product line.

The Peace Eagle program includes four 737 AEW&C aircraft plus ground support segments for mission crew training, mission support and system maintenance.

Modification of the first aircraft is under way at The Boeing Company facilities in Seattle. TUSAS Aerospace Industries (TAI) in Ankara, Turkey, will modify the remaining three aircraft.

Boeing Australia Limited is providing product support deliverables during the acquisition and initial support phases of the Peace Eagle program, including:

1. The initial training of the Turkish Air Force

2. The training of personnel from Turkish Industry to assume responsibility for in-service product support activities.

Boeing Australia Limited, as a subcontractor to The Boeing Company, is also designing and providing construction oversight for the ground support centre facility in Ankara Turkey, where the Peace Eagle's ground support segments will be installed.

Boeing Australia Limited's role in the Peace Eagle Project will conclude in 2012.

Figure 5. Turkish AEW&C Aircraft (Wikipedia)

Turkey participates to the Project “Peace Eagle” with her defense company, HAVELSAN.

HAVELSAN developed unique software modules for the mission processor, tactical display, communication and man-machine interfaces. HAVELSAN also is testing this software and working for integration of this software to the 737 AEW&C aircraft.

HAVELSAN participates in all the engineering processes throughout the program, starting from the system analysis untill the end of system test and evaluation. In the scope of the program, HAVELSAN develops, modifies and integrates 12 software modules.

The main responsibilities of HAVELSAN are :
• System Analysis and Design of Turkish unique modifications,
• Mission Computing Segment software Turkish unique design, development, integration and testing,
• Ground Support Segment software Turkish unique design, development, integration and testing,
• Hardware and software integration for the Ground Support Segment, which is composed of the Software Support Center, Mission Support Center and Mission Simulator,
• Software Development Laboratories (SDL) and System Integration Laboratories (SIL) operation in Turkey,
• System test and evaluation,
• Integrated Logistics Support (ILS) for the MCS and GSS throughout the service life of the system.
(http://eng.havelsan.com.tr/eng/activities/exp/main_exp/bk.php)

1.3.5 Problem Statement

The TUAF was using only ground RADARs as its early warning system against threats. Because of the shortage of ground RADAR coverage in some critical locations, the TUAF decided to procure AWACS aircraft to improve coverage and detect threats far away from its homeland.

The main problem is to find optimal locations of available AWACS aircrafts' orbits to obtain maximum coverage. The next step is to increase the number of AWACS to cover all of Turkey's borders. Thus, the research determines how many more AEW&C aircraft are needed to cover all of Turkey's borders as far from the borders as possible. Some assumptions and limitations are made to facilitate problem modeling and solution.

1.3.6 Assumptions and Limitations

In the problem, some SAM sites are located near Turkey's borders without Turkey's knowledge and because of that there can be pop-up threats and SEAD aircraft may not be effective enough to eliminate the SAM sites. Another important issue is that

there is always going to be Electronic Counter Measure (ECM) in the battle zone. The detection range of the AEW Aircraft is effected by ECM.

If the threat is expected to come from the west, the assumptions are:

1. SAM threats could be S-300 PMU2 and MIM-104 PATRIOT PAC-2
2. The Range of S-300 PMU2 is 91 NM and the range of MIM-104 PATRIOT PAC-2 is 95 NM.
3. Bad weather conditions are assumed. In bad weather conditions, the AEW&C aircraft's detection rage decreases to 200 NM.
4. The expected threat from the west includes the threat from the Aegean Sea, the Mediterranean Sea and north west part of the country.
5. The number of AEW&C aircraft is four.

If the threat is expected to come from the east, the assumptions are:

1. SAM threat could be S-300 PMU2.
2. The Range of S-300 PMU2 is 91 NM.
3. Bad weather conditions are assumed. In bad weather conditions, the AEW&C aircraft's detection range decreases to 200 NM.
4. The expected threat from east includes the threat from east, south east and north east parts of the country.
5. The number of AEW aircraft is four.

1.3.7 Research Objectives

The goal is to find the optimum locations of AEW&C aircraft orbits and the additional number of AEW&C aircraft Turkey needs to cover all borders.

1.4 Summary

As mentioned above air defense and early warning is a vital issue for a country. Some difficulties like ECM, bad weather, other country's defense system and long range missiles can be encountered. These difficulties are going to limit the airspace that AWACS uses, and thus detection ranges decrease.

1.5 Thesis Organization

This thesis includes five chapters. Chapter 2 presents a literature review. Information about the Turkish AEW&C aircraft, evolution of location problems and methods to solve the location problems are presented in Chapter 2. Chapter 3 presents the methodology to solve the problem. Results and analyses are discussed in Chapter 4. Finally Chapter 5 presents the conclusion, recommendations, and possible future research.

II. Literature Review

2.1 General

This chapter presents some specifications of the Turkish AWACS, evolution of location problems, and methods to solve location problems. The literature review presents information from journals, articles, and other information sources.

2.2 Specifications of Turkish AEW&C Aircraft

Boeing 737-700 AEW&C:

- Increased gross weight (IGW) airframe
- Northrop Grumman "MESA" electronically scanned array radar system

- 360 degrees/Air and Maritime modes/200 + NM range/All Weather
- IFF: 300 NM

- Open system architecture/COTS
- 6 to 10 multirole/purpose consoles
- System Track Capacity: > 3,000
- Precision Tracker
- Operational ceiling: 41,000 ft
- Range: 3500 NM
- Flight Crew: 2
- Mission Crew: 6 to 10 (www.boeing.com)

2.3 Facility Location Problems

Facility location is one of the most important topics in peoples' lives. Humans have been analyzing the effectiveness of locational decisions since they inhabited their first cave (Drezner, Z. Hamacher, Horst W. 2002). The location problem dates back to the 1600s. The first proposition of the problem is usually credited to Pierre de Fermat. Pierre de Fermat (1601-1665) threw out the challenge: "Let he who does not approve of my method attempt the solution of the following problem: Given three points in the plane, find the fourth point such that the sum of its distances to the three given points is a

minimum. In the twentieth century, the problem passed to those who claimed there was a use for it. In 1909, Alfred Weber used a weighted three point version of the problem to depict industrial location minimizing transport cost and this was the first formal introduction of the location problem (Drezner, Klamroth, Schöbel and Wesolowsky, 2002). A number of authors considered the problem of facility layout and design in the 1950s and 1960s (Alkanat, O., 2008).

Today, location problems have a wide range of application areas. These problems have been solved to locate the vital service providers such as fire stations and other emergency services in cities, numerous regular service providers such as bus stations, telecommunication switching centers and warehouses (Alkanat, O., 2008). There are also military applications of location problems. For example, locating RADAR sites and Surface to Air Missile (SAM) sites. Location problems are not limited to only locating the ground service providers on the earth; they also are used to locate the orbits of satellites in space and aircraft in airspace.

Since there are many different types of location problems, “for more than 120 years, mathematicians, analysts, operations researchers, and management science scholars have tried to devise algorithms and techniques to identify optimal locations given a wide variety of problem parameters, resource constraints, and model objectives.” (Eberlan 2004).

The goal of the location problem is to position facilities on points on a plane or a network to minimize some cost function or to maximize the number of satisfied demand

points. There are various kinds of location problems and some of these are introduced briefly.

2.4 Basic Facility Location Problems

Some basic facility location problems such as p-median, p-center, p-dispersion and, covering location problems are briefly discussed in this section.

2.4.1 P-Median Problem

The theory of the p-median problem dates back to the 1960s. The goal of the problem is to find the locations of p facilities to minimize the demand-weighted total distance between demand nodes and the facilities to which they are assigned (Current, Daskin, Schilling, 2002). In 1963, Cooper developed the classic facility location problem on a plane, which minimizes costs for a multiple location network, and he used a heuristic approach to minimize the shipping costs. This problem was named p-median problem. Several algorithms have been proposed for the p-median problem, including exact methods based on linear programming, constructive algorithms, dual based algorithms, and local search procedures. Hakimi formulated the problem for locating a single and multi-medians in 1965. He also proposed a simple enumeration procedure to solve the problem (Senne and Lorena). The problem is NP-hard on general graphs and networks if p is variable. Polynomial time algorithms exist for arbitrary p when the network is a tree (Resse, 2005). The p-median problem can be solved in polynomial time for fixed values of p (Garey and Johnson, 1979).

2.4.2 P-Center Problem

The p-center problem (Hakimi, 1964, 1965) minimizes the maximum distance demand is from its closest facility, given that there are a pre-determined number of facilities (Current, Daskin and Schilling, 2002). This model is used in various location problems such as, locating fire stations or hospitals, where the response time is minimized between the client and the center (Krumke, 1995). Vertex p-center problems and the absolute p-center problem are two versions of the basic model. In the vertex p-center problem, candidate facilities can be located on the nodes of the network, while the facilities can be located anywhere along the arcs in the absolute p-center problem. Both of them can be unweighted or weighted, and also can be solved as capacitated and uncapacitated location problems. All the demand nodes have equal values in the unweigthed model. The demand nodes' values and the distances between the demand nodes and facilities are multiplied in the weigthed model. The p-center problem is an NP-hard problem (Meddigo and Supowit, 1984).

2.4.3 P-Dispersion Problem

The goal of the p-dispersion problem is to locate p facilities at some of n predefined locations, such that distance between any pair of facilities is maximized. Potential applications of the p-dispersion include telecommunication to disperse the transceivers in order to minimize the interference problems, location of shops and service stations to minimize the mutual competition and the sighting of military installations where separation makes them more difficult to attack. The P-dispersion problem is known to be NP-hard (Erkut E., Ülküsal, Y., Yeniçerioğlu, O., 1994).

2.4.4 Covering Location Problems

The goal of the covering location problem is to locate a minimum number of supply points that cover all of the demand points. A demand point is said to be covered by a supply point if the demand point is within the range of supply point. This range is usually distance or time. Since this research concerns a covering location problem, two types of covering location problems, the set covering location problem (SCLP) and the maximal covering location problem (MCLP), are discussed.

Set Covering Location Problem

The SCLP determines the minimal number of facilities that are necessary to attend the demand points for a given covering distance (Preira, Lorena and Senne, 2007). The problem was introduced by Toregas et al. in 1971. The SCLP allocates each demand point to at least one facility and not necessarily to the closest facility. The SCLP is an NP-hard problem (Garey and Johnson, 1979) and can be formulated as follows:

$$\text{Minimize} \quad \sum_{j \in J} x_j \qquad (1)$$

Subject to:

$$\sum_{j \in N_i} x_j \geq 1 \quad \forall i \in I \qquad (2)$$

$$x_j \in \{0,1\} \quad \forall j \in J \qquad (3)$$

Where:

I = the set of demand nodes,

i = index of the demand points

J = the set of candidate facility location points,

j = index of the candidate facility points

d_{ij} = distance from demand point i to candidate facility point j

S = maximum coverage distance

$N_i = \{ j \mid d_{ij} \leq S \} \ \forall \ i \in I$ = the set of all candidate facility points that can cover demand point i

$$x_j = \begin{cases} 1, \text{ if } j^{\text{th}} \text{ candidate facility is located} \\ 0, \text{ otherwise} \end{cases}$$

The objective function (1) minimizes the number of facilities that cover all demand points. Constraint (2) provides that each demand point is covered by at least one candidate facility within the distance S. Constraint (3) forces the decision variables to be binary.

Maximal Covering Location Problem

The MCLP has proved to be one of the most useful facility location models from both theoretical and practical points of view (Marianov and ReVelle, 1995). The problem was originally introduced by Richard Church and Charles ReVelle in 1974. The MCLP is the problem of locating p facilities on a network such that the maximal population is attended (or covered) within a given service distance (Church and ReVelle, 1974). The MCLP is also NP-hard (Meddigo, Zemel and Hakimi, 1983). Various heuristic approaches have been developed to solve the problem efficiently. A useful approach is lagrangean relaxation embedded within a branch and bound algorithm (Drezner and Hamacher, 2002).

The problem of this research is formulated as an MCLP and an optimization approach is used. The classical MCLP can be formulated as follows:

$$\text{Maximize} \sum_{i \in I} a_i y_i \tag{4}$$

Subject to:

$$\sum_{j \in N_i} x_j - y_i \geq 0 \qquad \forall i \in I \tag{5}$$

$$\sum_{j \in J} x_j \leq p \qquad \forall i \in I \tag{6}$$

$$x_j \in \{0,1\} \qquad \forall j \in J \tag{7}$$

$$y_j \in \{0,1\} \qquad \forall i \in I \tag{8}$$

Where:

I = the set of demand nodes,

i = index of the demand points

J = the set of candidate facility location points,

j = index of the candidate facility points

d_{ij} = distance from demand point i to candidate facility point j

S = maximum coverage distance

p = the maximum number of facilities to locate

a_i = value of demand point i

N_i = $\{ j \mid d_{ij} \leq S \} \; \forall i \in I$ = the set of all candidate facility points that can cover demand point i

$$x_j = \begin{cases} 1, \text{ if } j^{\text{th}} \text{ candidate facility is located} \\ 0, \text{ otherwise} \end{cases}$$

$$y_i = \begin{cases} 1, \text{ if } i^{\text{th}} \text{ demand point is covered} \\ 0, \text{ otherwise} \end{cases}$$

The objective function (4) maximizes the sum of the covered demand point values. Constraint (5) forces non-coverage of demand point i if the candidate facilities j that cover demand point i are not located. Constraint (6) limits the number of facilities. The number of facilities means number of AEW aircraft, for this research. Constraint (7) and constraint (8) force the decision variables to be binary.

2.5 Solution Methods

The location problems can be solved by either heuristic or optimization methods. Large size problems have been attempted to be solved usually with heuristic methods by conceding the best solution. Heuristic methods usually provide a shorter solution time than optimization methods in large size problems. On the other hand these methods do not guarantee optimality. The Greedy Add Heuristic was developed by Kuehn and Hamburger, (1963) to locate facilities incrementally by least cost until p facilities are located . The Greedy Drop Heuristic was developed by Feldman, Lehrer and Ray in 1966. Greedy Drop starts with facilities located at all potential sites, and then removes (drops) the facility that has the least impact on the objective function (Current, Daskin and Schilling). One of the well-known heuristics, the neighborhood search algorithm, was improved by Marazana in 1964. The most widely known improvement method, the

interchange approach, was introduced by Teitz and Bart in 1968. The basic idea of the interchange method is to move a facility from the location it occupies in the current solution to an unused site. Each unused location is tried and when no better solution can be found, the procedure stops. Church and ReVelle developed two heuristic procedures, the Greedy Adding and the Greedy Adding with Substitution algorithms, to solve the MCLP. These algorithms are similar to vertex addition and substitution algorithms, developed for other location problems such as the simple plant location problem and the p-median problem (Galvao and ReVelle, 1993). Linear programming (LP) was also applied by Galvao and ReVelle to solve the MCLP. Optimality was guaranteed only if the LP solutions were all binary. Galvao and ReVelle also used a lagrangean relaxation technique. One of the primary attractions of this technique is that it provides both upper and lower bounds on the objective function's value (Fisher, 1981).

The simplex algorithm with branch and bound is the primary algorithm used today. (Nemhause, G., Wolsey, L., 1988).

2.6 Similar Problems

Location of aircraft has not been given much attention. A similar application was researched by Douglas E. Fuller in 1997. He wanted to locate surveillance aircraft on Iraq and South Korea using Ignizo's heuristic. Ignizo's heuristic utilizes a basic greedy procedure (Fuller, 1997). Optimization is used to solve the problem of this research.

2.7 Candidate Orbit Point Generation

Candidate orbit point (COP) generation for aircraft replacement on an entire plane has not received much attention (Fuller, 1997). Candidate points were known or given in most approaches in the literature. A COP generation method is needed to determine the COPs. There are two methods used to generate COPs. The first method is the circle method introduced by Mehrez and Stulman in 1982. The other method is laying a square grid over the location area and using the corners of each grid square as COPs (Fuller, 1997).

2.7.1 Circle Method

A method to generate a finite candidate solution set on an infinit plane was developed by Mehrez and Stulman (Fuller, 1997). They took candidate points as the intersection points of the circles drawn a certain radius around each demand point. This solution set often placed the candidate points at the farthest possible locations from the demand points. This is a good result from the viewpoint of this research. However, the maximum number of intersection points generated by this method is $2\binom{m}{2}$, where the number of demand points is m (Fuller, 1997). This means for 50 demand points 2450 COPs are generated and for 1000 demand points approximately one million COPs would be generated using this method. This method was not used because of the large numbers of COPs.

2.7.2 Grid Method

A grid is laid over all the demand points in this method. The grid's size is determined by the size of the geographic region to be covered (Fuller, 1997). In this research, the grid size is determined by the maximum covering distance that the AEW&C aircraft can see. Another factor is the spacing between the grid points. In order to avoid missing the demand points, this spacing should be set to a distance less than the orbit radius of the AEW&C aircraft. The grid method is explained in Chapter 3.

2.8 Matlab® Mapping Toolbox™

The Mapping Toolbox™ consists of an extensive set of functions and graphical user interfaces (GUIs) for creating map displays and analyzing and manipulating geospatial data in the MATLAB environment. Maps that combine different types of data from multiple sources can be created and displayed in their correct spatial relationship. Spatial analysis methods such as line-of-sight calculations on terrain data and geographic computations that count the curvature of the Earth's surface are supported by the toolbox. Its library of map projections and georeferencing utilities gives precise control over projected and unprojected coordinate systems. Since most Mapping Toolbox™ functions are written in open MATLAB® language, algorithms can be inspected and adapted to create custom functions.

Briefly summarized, the toolbox provides functionality in the following areas:

- Geospatial data import and access
- Vector map data and geographic data structures
- Georeferenced images and data grids
- Map projections and coordinates
- Map display and interaction
- Geographic calculations for vector and raster data

- A map viewer and other graphical user interfaces (Mapping Toolbox 2 user's Guide)

Here are some examples of what can be done using Mapping Toolbox™:

Figure 6 shows an example of a map, without an application of a projection, and grids drawn at 15 NM intervals..

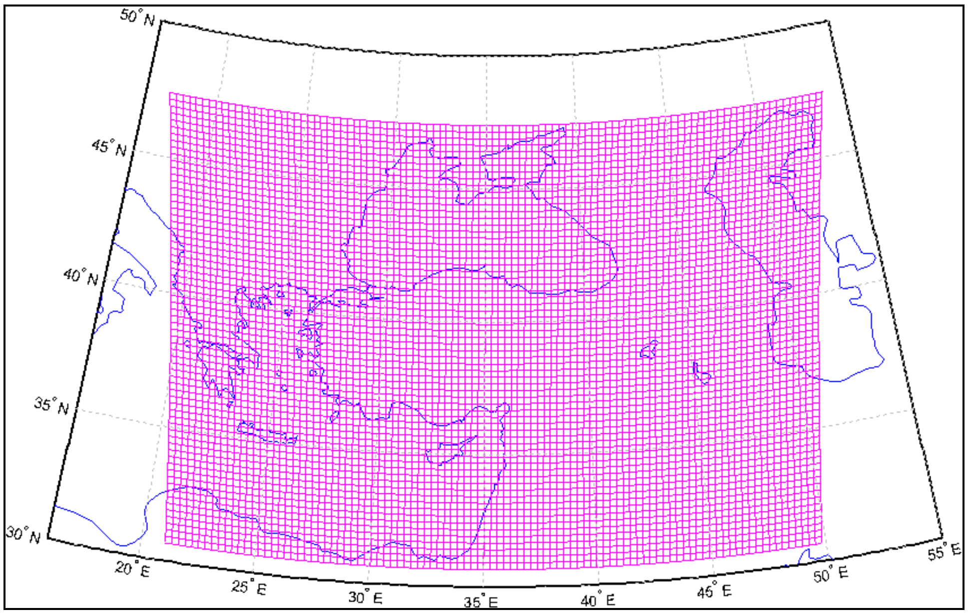


Figure 6. Map and Grids Drawn without a Projection

Figure 7 shows a map, projected using Mercator projection and grids drawn 15 NM intervals.

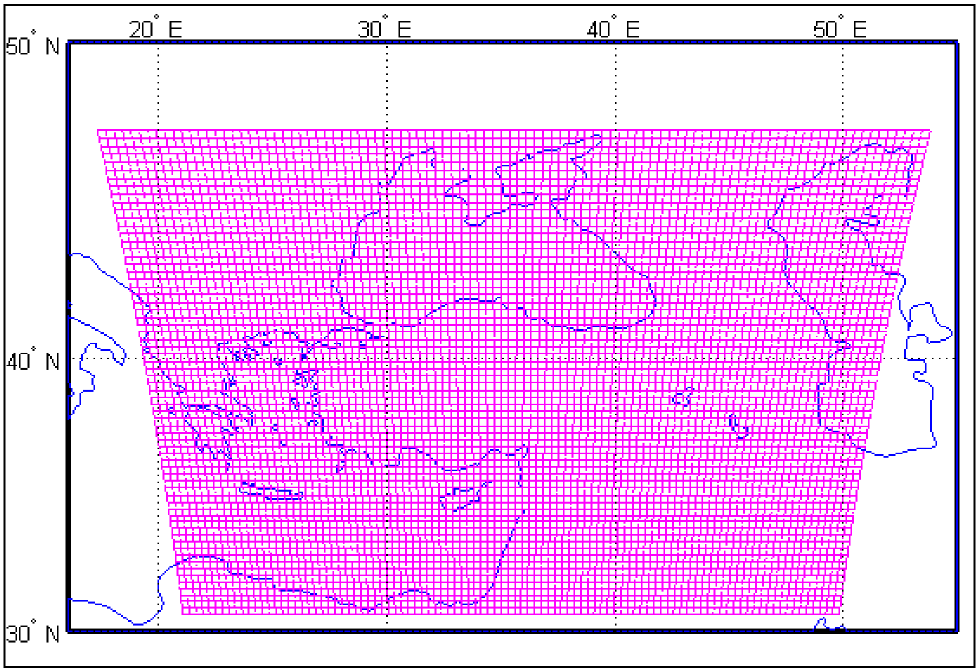


Figure 7. Map and Grids Drawn with Mercator Projection

Figure 8 shows an example which measures the great circle distance from Istanbul to New York City and draws a red colored great circle distance track.

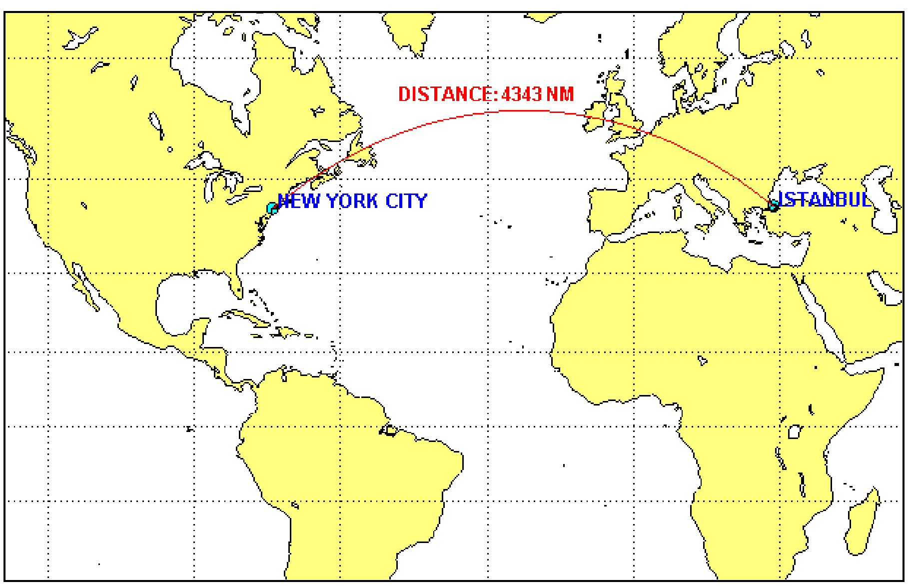


Figure 8. Great Circle Distance Example

For more information, please refer to MATLAB® Mapping ToolboxTM User's Guide on http://www.mathwoks.com/access/helpdesk/help/pdf_doc/map/map_ug.pdf.

2.9 MATLAB® Optimization Toolbox™

The capability of MATLAB® numeric computing environment is extended by the Optimization Toolbox™ software.

- Unconstrained nonlinear minimization
- Constrained nonlinear minimization, including semi-infinite minimization
- problems
- Quadratic and linear programming
- Nonlinear least-squares and curve fitting
- Constrained linear least squares
- Sparse and structured large-scale problems, including linear programming
- and constrained nonlinear minimization
- Multiobjective optimization, including goal attainment problems and
- Minimax problems

The toolbox also includes functions for solving nonlinear systems of equations. (MATLAB® Optimization Toolbox™ User's Guide)

In this section, only two optimization commands, 'linprog' and 'bintprog' are explained. For further information please refer to MATLAB® Optimization Toolbox™ User's Guide on http://www.mathwoks.com/access/helpdesk/help/pdf_doc/optim/optim_tb.pdf.

2.9.1 'linprog' Command

The command 'linprog' solves the linear programming problems. It finds the minimum of a problem specified by:

Min f(x) (9)

Subject to:

$Ax \leq b$, (10)

$$Aeqx = beq, \qquad (11)$$

$$lb \leq x \leq ub, \qquad (12)$$

A is the matrix that contains the coefficients of equations of the inequality constraints and b is the vector that contains the inequality constraint limit. Aeq is the matrix that contains the equality constraints' coefficients and, beq is the vector that contains the equality values of the equality constraints. Equation (9) is the optimization problem, equation (10) is the inequality constraint, equation (11) is equality constraint and equation (12) shows the lower bound (lb) and upper bound (ub) of variable x. Explanation of using the 'linprog' command is in Appendix A.

2.9.2 'bintprog' Command

The usage and the syntax of the 'bintprog' are the same as 'linprog'. The only difference is 'bintprog' solves a binary integer program. 'bintprog' uses a linear programming (LP) based branch and bound algorithm to solve binary integer programming problems. The 'bintprog' algorithm searches for an optimal solution by solving a series of LP-relaxation problems. Explanation of using the 'bintprog' command is in Appendix A.

2.10 Summary

In this chapter, general information is given about Turkish AEW&C aircraft followed by a discussion about facility location problems. Basic facility location problems are then reviewed. Methods used to solve the location problems and similar problems of this research are also discussed. COP generation methods are also presented. Lastly MATLAB® Optimization Toolbox™ and Mapping Toolbox™ are introduced.

III. Methodology

3.1 Introduction

This chapter presents the methodology used to solve the problem of determining the optimum orbit points of Turkish AEW&C aircraft, to maximally cover the outer sides of Turkey as far away as possible from her borders. First, a description of the problem is introduced and then the mathematical models are discussed. This is followed by the generation of the grids and generation of the map of Turkey. After that, the generation of the demand points and generation of the candidate points are reviewed. Then, implementation of the preprocessing constraints to eliminate COPs is discussed. Subsequently, the generation of the formulation in MATLAB® is covered. Finally a summary of this chapter is presented.

3.2 Problem Description

The TUAF wants to determine the optimal orbit points of Turkish AEW&C aircraft in Turkey's airspace. This problem can be modeled as a modified MCLP. The AEW&C aircraft is not fixed at only one point, the aircraft must be constantly moving. The normal operational orbit radius is taken as 15 NM (Fuller, 1997). The aircraft's ability to cover the demand points from both sides of its orbit is taken under consideration. There are some additional constraints which restrict the operational area of the AEW&C aircraft, under a risk that can be taken by the theater commander. The aircraft cannot be located at a candidate orbit point (COP) which has a risk higher than the risk the commander has taken under consideration. The AEW&C aircraft cannot

protect itself from hostile attack. The aircraft must be escorted by friendly fighter aircraft. Thus, AEW&C aircraft cannot be located at an orbit point which is out of the range of the friendly fighter support.

3.3 Risk

The risk, introduced in this research, means the probability of AEW&C aircraft's vulnerability at candidate orbit point j (COP_j). The risk at each COP is denoted as Rc_j. The risk that the commander takes under consideration is denoted as R. The AEW&C aircraft cannot be located at an orbit points which has risk higher than the risk taken under consideration by the commander. This can be formulated as $Rc_j x_j \leq R \ \forall j \in J$.

SAM sites and the hostile airfields which are located near the border of Turkey cause the risk. The risk exists at the COPs which are on and near the borders of the country even if there is no adversary SAM site or hostile airfield known close to the country, since an unknown threat can always exist outside the borders.

3.4 Mathematical Model

Incorporating the risk constraints explained above, the mathematical model can be developed by modifying the basic MCLP formulation. The modified MCLP formulation is:

$$\text{Maximize} \quad z = \sum_{i \in I} a_i d_i \tag{13}$$

Subject to:

$$\sum_{j \in N_i} COP_j - d_i \geq 0 \qquad \forall i \in I \tag{14}$$

$$\sum_{j \in J} \mathrm{COP}_j \leq p \qquad \forall i \in I \tag{15}$$

$$\mathrm{Rc}_j \mathrm{COP}_j \leq \mathrm{R} \qquad \forall j \in J \tag{16}$$

$$\mathrm{D}_j \mathrm{COP}_j \leq \mathrm{RLFB}_f \qquad \forall j \in J \ \& \ \forall f \in F \tag{17}$$

$$\mathrm{COP}_j \in \{0,1\} \qquad \forall j \in J \tag{18}$$

$$\mathrm{d}_j \in \{0,1\} \qquad \forall i \in I \tag{19}$$

Where:

I = The set of demand nodes,

i = Index of the demand points

J = The set of COPs,

j = Index of the candidate points

F = The set of friendly fighter bases,

f = Index of the friendly fighter bases

δ_{ij} = Distance from demand point i to COP j

S = Maximum coverage distance

p = The number of COPs to occupy

a_i = Value of the demand point i

Rcj = Risk at the j^{th} COP

R = Risk taken under consideration by commander,

D_{jf} = Distance from jth COP to friendly fighter base f.

D_j = min D_{jf} $\forall j$ & $\forall f$.

$RLFB_f$ = Range limit of friendly fighter base f.

$N_i = \{ j \mid \delta_{ij} \leq S \} \ \forall\, i \in I$ = the set of all candidate orbit points that can cover demand point *i*.

$$COP_j = \begin{cases} 1, \text{ if AEW\&C aircraft is located at } j^{\text{th}} \text{ COP} \\ 0, \text{ otherwise} \end{cases}$$

$$d_i = \begin{cases} 1, \text{ if } i^{\text{th}} \text{ demand point is covered} \\ 0, \text{ otherwise} \end{cases}$$

Objective function (13) maximizes the sum of the covered demand points' values. Constraint (14) ensures that demand point *i* is not included if a candidate orbit point *j* that covers demand point *i* is not occupied. Constraint (15) limits the number of AEW&C aircraft available. Constraint (16) ensures the the risk at COP_j is less than or equal to the risk commander accepts (R). Constraint (17) eliminates the COPs out of the range of the nearest friendly fighter base *f*. Constraint (16) and constraint (17) are not MCLP constraints. These constraints are for preprocessing to eliminate the COPs which do not meet the required limits. After preprocessing, constraint (16) and constraint (17) can be removed from the formulation. Constraints (18) and (19) are the integrality constraints.

3.5 Generation of the Grid Squares

The generation of grids is an important issue to provide accurate demand points and COPs to the model. The AEW&C aircraft's orbit radius is 15 NM, hence 15 NM by 15 NM grids are drawn to reflect the aircraft's orbit radius. Generating the grids by drawing straight lines cannot provide equal distances. In order to generate 15 NM by 15 NM grids, the center coordinate of the country is taken as the origin. Four data

coordinates are needed to establish the center of the country and the number of parallels and meridians to be drawn. Two of these data are latitudes and the other two data are longitudes. One of the latitudes needed is the latitude of the farthest point of the country to the north and the other latitude is the farthest point's latitude to the south. One of the longitudes needed is the longitude of the farthest point of the country to the west and the other longitude is the farthest point's longitude to the east. The farthest points are shown as red dots in Figure 9. The latitude of the center coordinate can be established by subtracting the latitude which is south of the country from the latitude which is north of the country. The result is divided by two, then added to the latitude which is south of the country and the latitude of the center is found. The same process is applied to establish the longitude of the center point. The center point is shown as blue dot in the Figure 9.

Then two straight lines originating from the center are drawn and they are represented as purple lines in Figure 9, are drawn to the north and to the south until the two latitudes which are mentioned above are reached. The green dots represent the end points reached. From these end points, the lines are continued to be drawn at the detection range of the AEW&C aircraft which is assumed to be 185 NM. The same process is applied to the west and to the east. The end points of the four lines found are the outer limits of the grids. These points are shown as black dots in Figure 9. Outer limits are shown as blue lines. After these processes, the latitudes of the outer limits are subtracted from the center point's latitude. 15NM is converted to degrees.

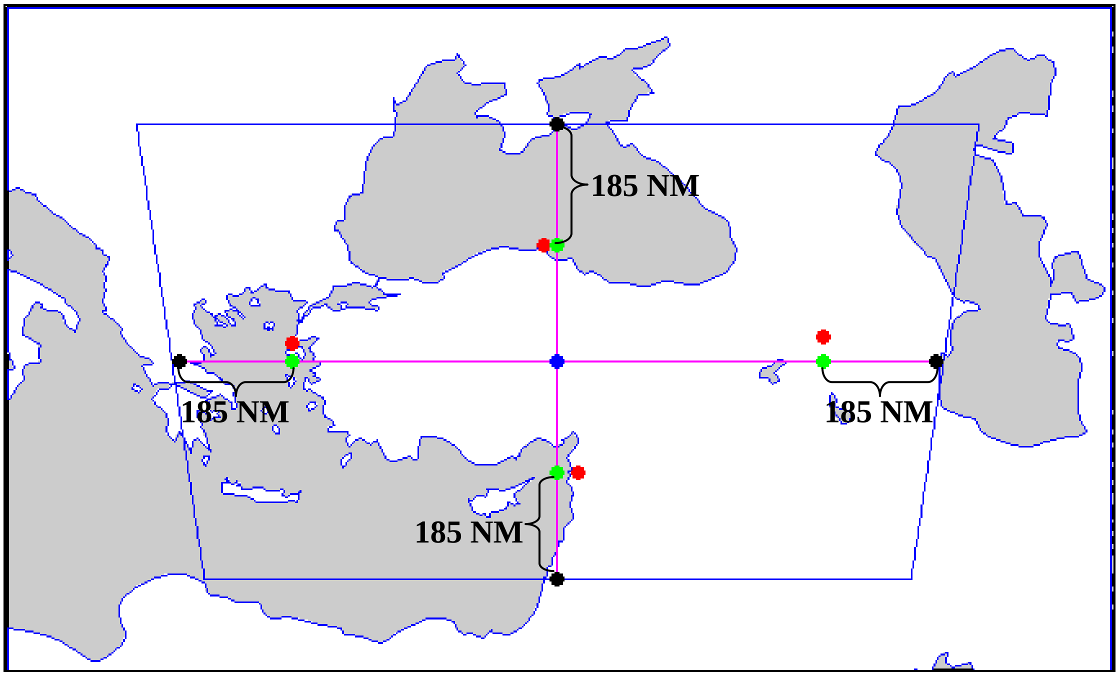


Figure 9. Illustration of the grid creation process using Mercator projection

The absolute values of the results of the subtractions are divided by 15 NM expressed as degrees. The ceiling of the results of the divisions gives the number of parallels to be drawn. The same process is applied to find the number of the meridians.

After determining the number of latitudes and longitudes, parallels are drawn gradually by 15NM increments. Every 15NM gives the latitudes and longitude coordinates. Figure 10, shows the grids drawn every 15 NM, for 185 NM range. Although equal 15 NM by 15NM squares are provided near the origin, as the distance increases from the center point, a distance error occurs and this error grows as the distance increases. However, this error is not large enough to be taken under consideration. The maximum error is 0.24 NM in the east and west.

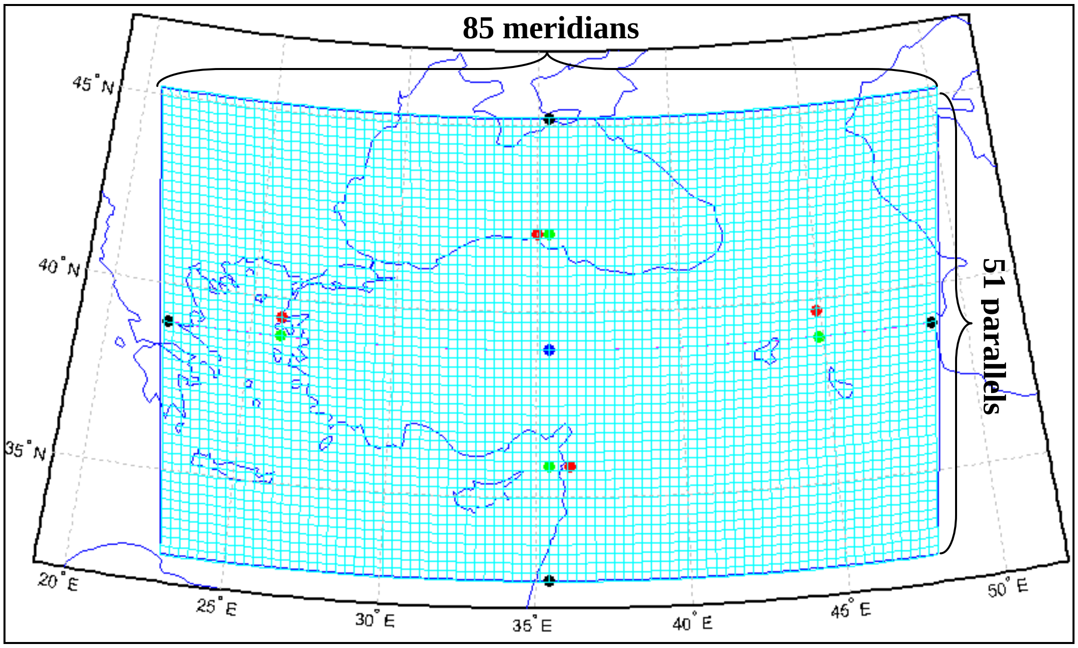


Figure 10. Illustration of the map without a projection after the grids are created

3.6 Generation of Turkey's Map

After creation of the grids, map generation is necessary to obtain the COPs and demand points. In order to create the map of the country, a manual process is needed. After the grids are created, border points of the country must be chosen by hand. Then the lands of the country are assigned to a 0-1 matrix by programming. Another way to assign the lands of the country to a matrix is by preparing the matrix in an Excel file. Then the file prepared is read by MATLAB® and assigned to a matrix. The latter method is used to obtain the map of Turkey. The illustration of the map is shown in Figure 11. Red cells in Figure 11 show the center point of Turkey. The lines of the cells represent the latitude and longitudes. Yellow cells show the lands of Turkey and 1s are assigned to those cells. Other cells keep 0s. After assigning the Excel matrix to a matrix in MATLAB®, four matrices are created. Two of the matrices are created to keep the grid data after the grid

creation explained in the previous section. The first matrix keeps the latitude data and the second matrix keeps the longitude data. The third matrix is created to enumerate candidate orbit points and the fourth matrix is created to enumerate the demand points.

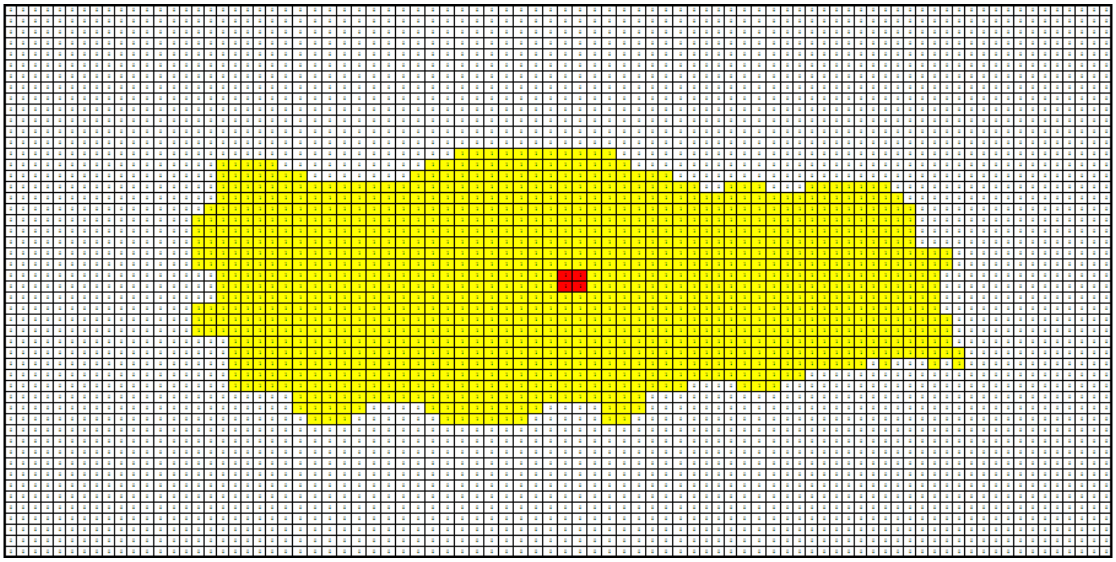


Figure 11. Illustration of map of Turkey in Excel matrix

3.7 Demand Point Generation

Demand points are not treated as targets in this research. Demand points are the intersections of the parallels and meridians out of the lands of Turkey. However, if desired, special targets can be chosen as demand points.

After creating the map matrix of Turkey, a demand point matrix that keeps the number of each demand point is created as mentioned above. A demand point elimination process is applied to exclude the demand points that cannot be covered even if AEW&C aircraft are located at every point on the border of the country. A matrix which keeps the coordinates and number of each demand point is created consequently. The structure of the demand point matrix is shown in Table 1.

Table 1. Example of Demand Point Matrix Structure

Latitute	Longitude	Number	Value
42.235	22.864	1	100
41.925	23.937	2	90
41.685	23.649	3	90
⋮	⋮	⋮	⋮

This structure aids including or excluding the demand points from the formulation. If a demand point is excluded, a ‘0’ is assigned to the demand point number column. If a demand point is included, then the order number of the demand point is written to the demand point column. Table 2 shows the change in the demand point matrix if a second demand point is excluded. If the second demand point is included again, then ‘2’ is going to be written in the demand point number column. When the demand point is excluded the value of that demand point also becomes ‘0’.

Table 2. Demand Point ‘2’ is excluded

Latitute	Longitude	Number	Value
42.235	22.864	1	100
41.925	23.937	0	0
41.685	23.649	3	90
⋮	⋮	⋮	⋮

3.8 COP Generation

In this research, COPs are the intersection points of the parallels and meridians which are within the lands of Turkey. COPs' data are assigned to a matrix by using the map of Turkey. Coordinates, COP numbers and total risk are kept within the COP matrix. The structure of the COP matrix is similar to the structure of demand points except for the risk column as shown in Table 3.

Table 3. COP Matrix Structure

Latitute	Longitude	Number	Risk
39.235	30.864	1	.54
37.925	34.937	2	.72
38.685	35.649	3	.25
⋮	⋮	⋮	⋮

This structure makes the elimination of COPs easier. When a COP is eliminated, the COP's number becomes '0'. When a COP is included, the COP's number becomes the order number again.

3.9 Computation of The Risk

The AEW&C aircraft cannot protect itself from hostile attack. Because of this, the aircraft is vulnerable and under risk. Data used to calculate the risk in this research does not reflect reality. In order to calculate the risk at each COP some assumptions are made. The assumptions are used to portray the scenarios similar to reality. Different

assumptions can be used to portray different scenarios. These assumptions are explained next.

3.9.1 Assumptions Used to Compute The Risk

Even if there are no SAM sites and hostile fighter air bases close to Turkey, some risks are defined for the COPs which are on the borders and near the borders, since there can be unknown threats. The COPs on the borders have the maximum risk. Risks are gradually decreased towards the lands of the country and at some point risk equals zero. Since the most secure part of the country is in Black Sea Region, the risk on the coast of Black Sea is taken as 20%. The region is defined by latitude and longitude limits. The risk of the borders out of this defined region is taken as 30%. The illustration of the risks defined for the borders is shown in Figure 12. Red dots show COPs with 30% risk, the yellow dots with red cross represent the land borders, orange dots show COPs with 20% risk, yellow dots show COPs with 10% risk and the black and blue dots show COPs with zero risk. Black dots also represent the outer line of the COPs with zero risk.

In order to portray the scenarios in a more realistic way, risks are defined inside of the SAM site, and hostile airfield ranges. For S-300 PMU-2, a 36 NM distance is defined with the risk of 100%. The risk gradually decreases each 5 NM distance by 10%, as the distance from the SAM increases. The critique distance defined for Patriot SAM system is 40 NM. The same risk reduction is used for the Patriot SAM system.

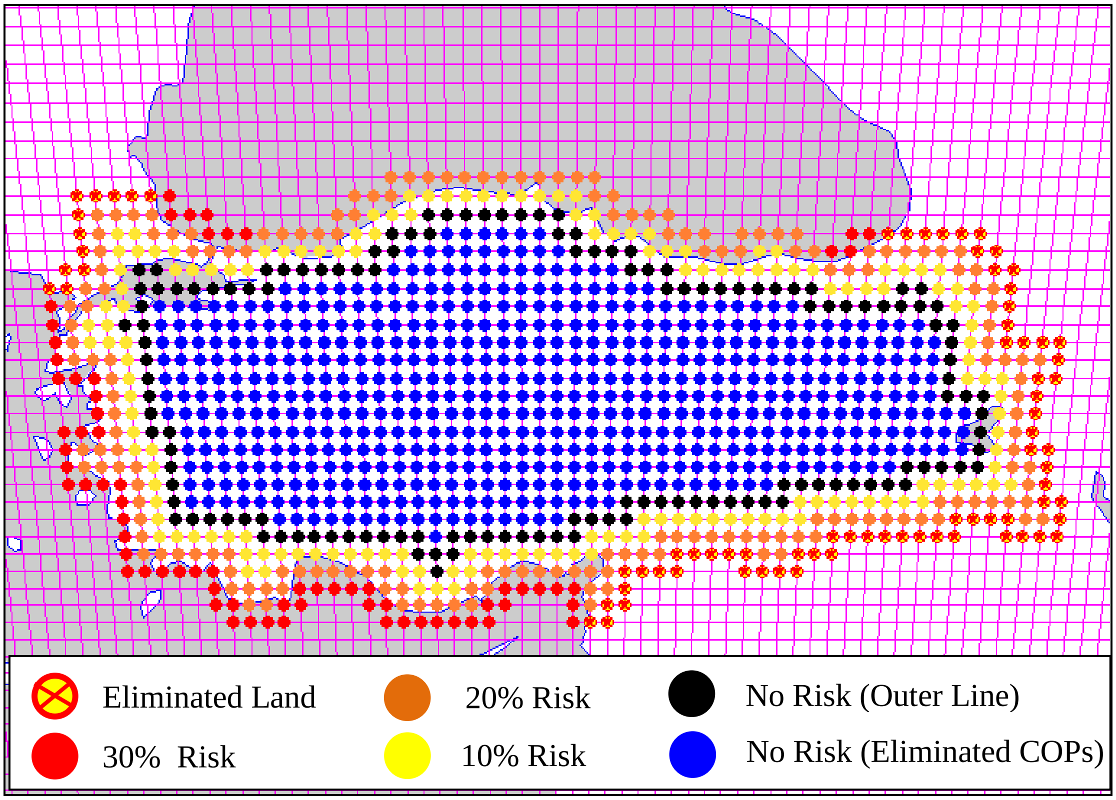


Figure 12. Risk Map of Turkey without Any Known Threat

Since the air speed of the adversary aircraft is less than a SAM missile's air speed and the range of adversary aircraft's missile is less than SAM missile range, the assumptions used for the adversary airbase are different from the assumptions used for adversary SAM systems. A 15NM range is defined as 100% risk for an adversary airbase. Escaping from the adversary aircraft's radar missile is not possible within 15NM. The risk reduces each 2.5 NM distance by 10%.

The above data is used under the assumption that Turkey has her own anti-missile and anti-aircraft defense systems. The AEW&C aircraft detects the adversary missile launch and reports the missile launch to the friendly anti-missile system to engage. Meanwhile AEW&C aircraft escapes from the missile with maximum speed. The friendly

anti-missile hits the hostile missile before it hits the AEW&C aircraft. On the other hand Suppression of Enemy Air Defense (SEAD) aircraft will protect the AEW&C aircraft from known adversary SAM sites. Friendly fighter aircraft protect the AEW&C aircraft against the adversary fighter aircraft. Different assumptions can be used. Adversary SAM sites and airbases are located using FalconView version 3.2 which is a special mapping system. The distances are measured using a great circle distance method.

3.9.2 Explanation of The Risk Computation

As mentioned above, there is always a risk close to the borders even if there are no known threats. If there is a known threat, risk increases. In order to obtain the new risk value, a risk computation is needed. Some definitions are introduced to explain the computation. The set of adversary SAM sites is denoted as M and m is the index of the SAM sites. Then the risk caused by SAM site m at COP_j is denoted as Rc_{mj}. The set of hostile fighter airbases is denoted as E and the index of the hostile fighter bases is denoted as e. Then the risk caused by adversary fighter air base e at COP_j can be denoted as Rc_{ej}. The existing risk at COP_j is denoted as Rc_j. Computed risk at COP_j is assigned as Rc_j again. The risk probabilities caused by the threats are mutually exclusive. The process can be explained by a simple example. Let the existing risk be 10%, the risk caused by adversary SAM site m is 30% and the risk caused by adversary fighter air base is 20% at COP_j. For this example, formulation can be shown as; $((\mathrm{Rc}_j \cup \mathrm{Rc}_{mj} \cup \mathrm{R}_{ej}) \setminus ((\mathrm{Rc}_j \cap \mathrm{Rc}_{mj}) \cup (\mathrm{Rc}_j \cap \mathrm{Rc}_{ej}) \cup (\mathrm{Rc}_{mj} \cap \mathrm{Rc}_{ej}))) \cup (\mathrm{Rc}_j \cap \mathrm{Rc}_{mj} \cap \mathrm{Rc}_{ej})$. Then risk equation is $(0.10 + 0.30 + 0.20) - ((0.10)(0.30) + (0.10)(0.20) + (0.30)(0.20)) + (0.10)(0.30)(0.20)) = 0.496$. The new vulnerability risk of the AEW&C aircraft at COP_j is 49.6%.

3.10 Elimination of The COPs

Preprocessing is applied to eliminate COPs. 1179 COPs are generated inside the borders of Turkey. COP elimination starts with checking each COP's distance to each friendly fighter airbase according to the constraint (17) in the mathematical model. Range of friendly fighter air base is assumed to be 100 NM. This range is made under the assumption that fighter aircraft escort the AEW&C aircraft for approximately 2 hours and 30 minutes. The route to the COP and return to home (RTB) takes about 20-30 minutes. Then the risk of each COP (Rc_j) is compared with the risk that the commander accepts (R). If $Rc_j \geq R$, COP_j is eliminated. R can be a risk value range, for example between 10%-20%, or can be a specific value such 30%. Since the goal is to cover outside the borders of Turkey, after the COP elimination process, COPs that are inside of the outer line composed by COPs with zero risk, are eliminated. There is no known threat in Figure 12 and black dots show the outer line of COPs with zero risk. Blue dotted COPs are the eliminated COPs . '0's are assigned to the COP number column of the excluded COPs in the COP matrix. This change effects the A matrix of the formulation and the changes in the A matrix is accomplished by removing the column *j* of A matrix related to eliminated COP *j*.

3.11 Generation of The MCLP Formulation in MATLAB®

After the elimination of COPs and demand points, the A matrix, the optimization function vector f, and b vector are generated.

3.11.1 Generation of A Matrix

The A matrix is generated according to the equation,

$\sum_{j\in N_i} COP_j - d_i \geq 0 \quad \forall i \in I$, which is constraint (14) in the modified MCLP formulation. In order to adapt the constraint to use in MATLAB® Optimization Toolbox® it must be multiplied by '-1'. Then the equation becomes

$\sum_{j\in N_i} -COP_j + d_i \leq 0 \quad \forall i \in I$. The A matrix is separated into two parts. One part consists of '0's and '-1's on the left and is named A_cop in the MATLAB® code. If d_i is covered by COP_j, then '-1' is assigned to A_cop(i,j), otherwise '0'. The columns on right part of the A matrix consists of '0's and '1's and is named A_dmd in the MATLAB® code. If COP_j covers d_i, then '1' is assigned to A_dmd(i,i), otherwise '0'. Then it can easily be seen that the second matrix is a matrix that has '1's on its diagonals. The other elements of the matrix are '0's. In this research the distances between demand points and COPs are measured as rhumb line.

After the processes above, the last row of the A matrix is created according to the equation, $\sum_{j\in J} COP_j \leq p \quad \forall i \in I$, which is constraint (15) of the modified MCLP formulation. The last row consists of '1's up to the number of COPs then '0's up to the number of demand points and is named as last_row in the MATLAB® code.

After the generation of A_cop, A_dmd matrices and the last_row vector, they are joined together to form the A matrix.

3.11.2 Generation of Objective Function Vector and 'b' Vector

Objective function vector 'f' consists of zeros reflecting the number of COPs, followed by the demand point values.

'b' vector consists of zeros until the number of demand points, then the number of AEW&C aircrafts to be located.

All these processes above can be explained by a simple example.

3.11.3 Example of Generation of The MCLP Formulation in MATLAB®

Let, J= { COP_1, COP_2, COP_3 } be the set of COPs, and I={ d_1, d_2, d_3, d_4, d_5, d_6} be the set of demand points and the value of each demand point is 100.

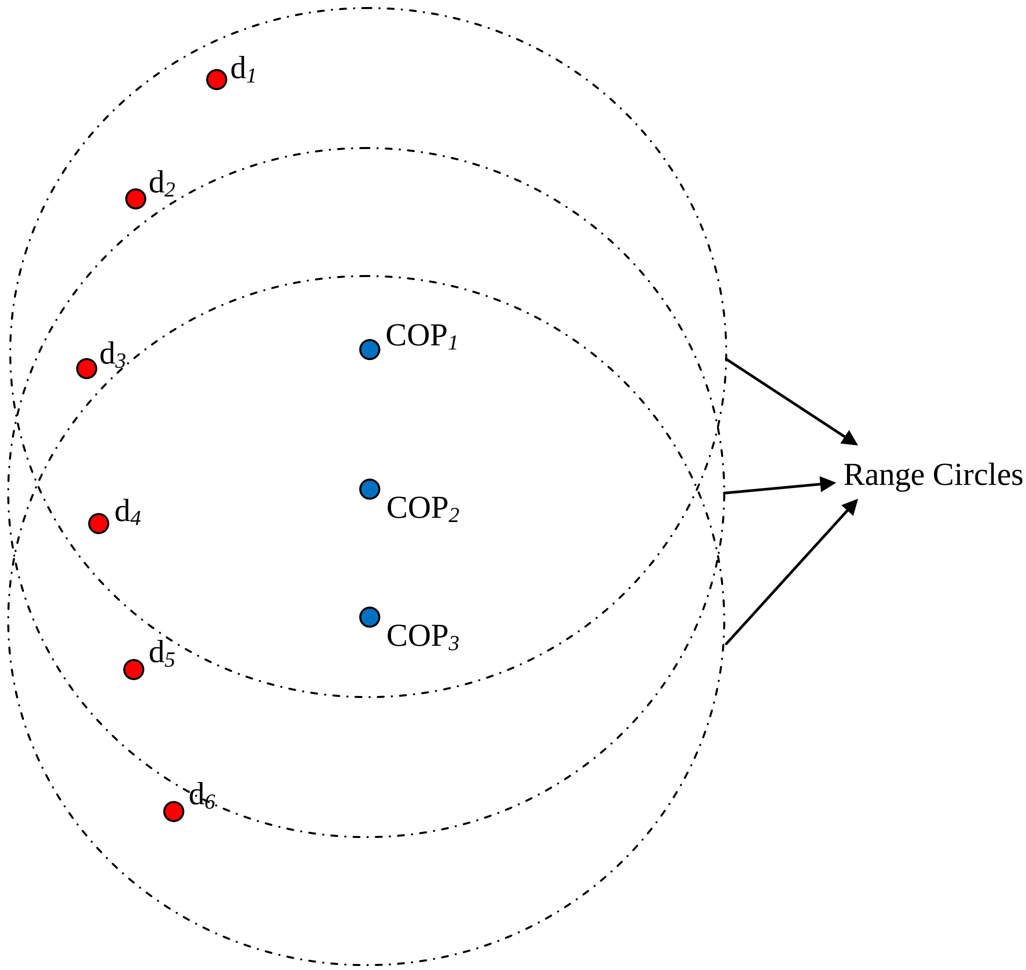


Figure 13. A simple example of COPs and Demand Points

In this example it is assumed that there are two AEW&C aircraft. According to Figure 14, the formulation can be shown in A x ≤ b format on the next page.

If the two AEW&C aircraft are located at COP_1 and COP_2, all the demand points are covered and this is the solution of the MCLP problem.

$$\text{Max } z = \overbrace{\begin{bmatrix} 0 & 0 & 0 & -100 & -100 & -100 & -100 & -100 & -100 \end{bmatrix}}^{f} \overbrace{\begin{bmatrix} COP_1 \\ COP_2 \\ COP_3 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \end{bmatrix}}^{x}$$

Subject to:

$$\overbrace{\begin{array}{c} \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \\ \\ \end{array} \begin{array}{c} \overbrace{\begin{array}{ccc} COP_1 & COP_2 & COP_3 \end{array}}^{A\_cop} \quad \overbrace{\begin{array}{cccccc} d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{array}}^{A\_dmd} \\ \begin{bmatrix} \begin{bmatrix} -1 & 0 & 0 \\ -1 & 0 & 0 \\ -1 & -1 & 0 \\ -1 & -1 & -1 \\ 0 & -1 & -1 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \\ \underbrace{\begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}}_{last\_row} \end{bmatrix} \end{array}}^{A} \overbrace{\begin{bmatrix} COP_1 \\ COP_2 \\ COP_3 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \end{bmatrix}}^{x} \overset{\le}{\le} \overbrace{\begin{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 2 \end{bmatrix} \end{bmatrix}}^{b}$$

3.12 Changes in Matrices

After the elimination of COPs, the A matrix's columns for each eliminated COP becomes a zero vector. When a demand point is excluded, the rows which belong to each excluded demand point becomes a zero vector. If a demand point is excluded, its value in objective function also becomes zero. In the above example if demand points d_3 and d_4 are excluded and COP_2 is eliminated, the matrices are as shown below.

$$\text{Max } z = \overbrace{\begin{bmatrix} 0 & 0 & 0 & -100 & -100 & 0 & 0 & -100 & -100 \end{bmatrix}}^{f} \overbrace{\begin{bmatrix} \quad \end{bmatrix}}^{x}$$

Subject to:

$$\overbrace{\begin{array}{c c} & \begin{array}{ccc ccccccc} COP_1 & COP_2 & COP_3 & d_1 & d_2 & d_3 & d_4 & d_5 & d_6 \end{array} \\ \begin{array}{c} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \\ \\ \end{array} & \left[\begin{array}{ccc|cccccc} -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 \\ \hline \underbrace{1 \quad\; 0 \quad\; 1}_{A\_cop} & & & \underbrace{0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0}_{A\_dmd} \end{array}\right] \end{array}}^{A}$$

$$\left[\begin{array}{ccccccccc} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right] \text{ (last\_row)}$$

$$\overbrace{\begin{bmatrix} COP_1 \\ COP_2 \\ COP_3 \\ d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \end{bmatrix}}^{x} \le \overbrace{\begin{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 2 \end{bmatrix} \end{bmatrix}}^{b}$$

The columns and rows with 0s are excluded from the A matrix. Two arrays are used to keep the COP numbers and demand point numbers to help determine which COPs are located and which demand points are covered after the exclusion of the rows and columns. The above example can be shown as follows.

$$\text{Max } z = \overbrace{\begin{bmatrix} 0 & 0 & -100 & -100 & -100 & -100 \end{bmatrix}}^{f} \overset{x}{\begin{bmatrix} \quad \end{bmatrix}}$$

Subject to:

$$\overbrace{\begin{array}{c c} \overbrace{\begin{array}{cc} COP_{1} & COP_{3} \end{array}}^{A\_cop} & \overbrace{\begin{array}{cccc} d_{1} & d_{2} & d_{5} & d_{6} \end{array}}^{A\_dmd} \end{array}}^{A} \qquad \overbrace{\quad}^{x} \quad \le \quad \overbrace{\quad}^{b}$$

$$\begin{array}{c} d_{1} \\ d_{2} \\ d_{5} \\ d_{6} \\ \\ \end{array} \begin{bmatrix} \begin{bmatrix} -1 & 0 \\ -1 & 0 \\ 0 & -1 \\ 0 & -1 \end{bmatrix} & \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ \multicolumn{2}{c}{\underbrace{\begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}}_{last\_row}} \end{bmatrix} \begin{bmatrix} COP_{1} \\ COP_{3} \\ d_{1} \\ d_{2} \\ d_{5} \\ d_{6} \end{bmatrix} \le \begin{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 2 \end{bmatrix} \end{bmatrix}$$

Since the generation of the A matrix takes a long time, while all the eliminations are being done, the original A matrix is kept and a temporary matrix is used to track changes. Keeping the original A matrix unchanged enables the changes to be applied easily in a short time.

3.13 Summary

In this chapter, the methodology used to solve the research's problem is presented. Risk is introduced, followed by the mathematical model of the research. Generation of grids, the map of Turkey, COPs and demand points are discussed. Then, assumptions used to calculate the risk and the computation of the risk were explained. After that, generation of the formulation in MATLAB® programming language was discussed. Finally changes in the matrices of the model, as the scenarios change were presented. Chapter 4 presents the results and the sensitivity analyses of the model.

IV. Results and Analysis

4.1 Introduction

This chapter explains and compares the results of three scenarios that are explained in the next section. The western scenario consists of the area which is west of the 35 degree longitude. The eastern scenario is east of the 35 degree longitude. The third scenario combines the west and the east scenarios. These scenarios are modeled and the results are analyzed. The optimization program was run on a SONY VAIO® VGN-SR290NTB with Intel® Core 2 Duo 2.26 Ghz CPU, 3 Gb memory. All the solution times are approximately less than 13 seconds.

4.2 Western Scenario

It is assumed that the threat from the west includes the Aegean Sea, the Mediterranean Sea and northwest part of the country. The west part of the Mediterranean Sea is considered as Mediterranean Sea. The north and the south part of the country are also taken under consideration. This is a wide area and the longest range of possible threat that can affect AEW&C aircraft is 95 NM. In this manner, the air space the AEW&C aircraft uses is limited. ECM and the weather conditions in the area affect the detection range of AWACS, and shorten it to 200 NM whereas it is 300 NM in the best environmental conditions.

The western scenario has 1159 demand points and 255 COPs before the elimination process. The cover range is defined as the maximum distance that a COP can be from a demand point and still cover the demand point. This distance should be set at

the AEW&C aircraft’s effective detection range minus the radius of the orbit. If the effective range of the AEW&C aircraft is 200, then the cover radius is set to 185NM.

Four AEW&C aircraft are available. Each COP is located approximately 15 NM apart. Initial A matrix is a 1160 by 1414 matrix before elimination process. Eleven Adversary SAM sites and eight adversary airbases are located close to the borders of Turkey to portray a realistic scenario. Three of eleven SAM sites are Patriot SAM systems, other eight SAM systems are S-300 SAM systems. Since the real number of the SAM systems is not known, the number of SAM sites is chosen for illustration purposes. Coordinates and numbers can be changed by user. It is assumed that the commander accepts risk up to 30%. The risk is gradually decreased to observe the effect on coverage.

It can easily be observed that the coverage distance in some regions is not far enough. In order to increase the minimum coverage distances, the aircraft are relocated and changes on the coverage rates and distances are analyzed.

Relocation is accomplished by forcing some demand points to be covered by the AEW&C aircraft. This means, additional constraints are applied to the MCLP model. In the western scenario, first priority is given to increase the minimum coverage distance on the Aegean Sea. Then the minimum coverage distance on the Mediterranean Sea is increased. The last priority is given to the north west part of the country. Minimum coverage distance desired on the north west is 75 NM. The minimum coverage distance desired on the Aegean Sea is 85NM, and on the Mediterranean Sea the desired distance is 80 NM. Another consideration is to keep the minimum coverage distances on the north and south at70 NM. Maximum coverage distance on the Aegean and Mediterranean Seas

is desired without decreasing the minimum 70 NM coverage distance on the north and the south. If the minimum coverage distance on the Aegean Sea, Mediterranean Sea and north west part of the country, can only be obtained by compromising the minimum coverage distance of the north or the south, this is acceptable.

If a minimum distance of 70 NM for the north and the south cannot be obtained while the minimum distance on the Aegean and the Mediterranean Seas are obtained, the minimum coverage distance on the Mediterranean Sea is accepted as approximately 75 NM, whereas it was 80NM.

Another consideration is to compare the gain and the loss of the coverage. For example, if the coverage on the Mediterranean Sea increases approximately 2 NM, whereas the coverage distance on the south decreases 5NM or more after the relocation, the aircraft which covers the south was not relocated.

Finally, the aircraft are located as far as possible from each other since close locations cause additional risk. Minimum of 150 NM distance between the aircraft is considered. The same processes are used for the eastern scenario and the combination of the western and eastern scenarios.

The western scenario’s results and the analyses according to the risks are presented in the next sections.

4.2.1 Results and Analysis of Western (30% Risk)

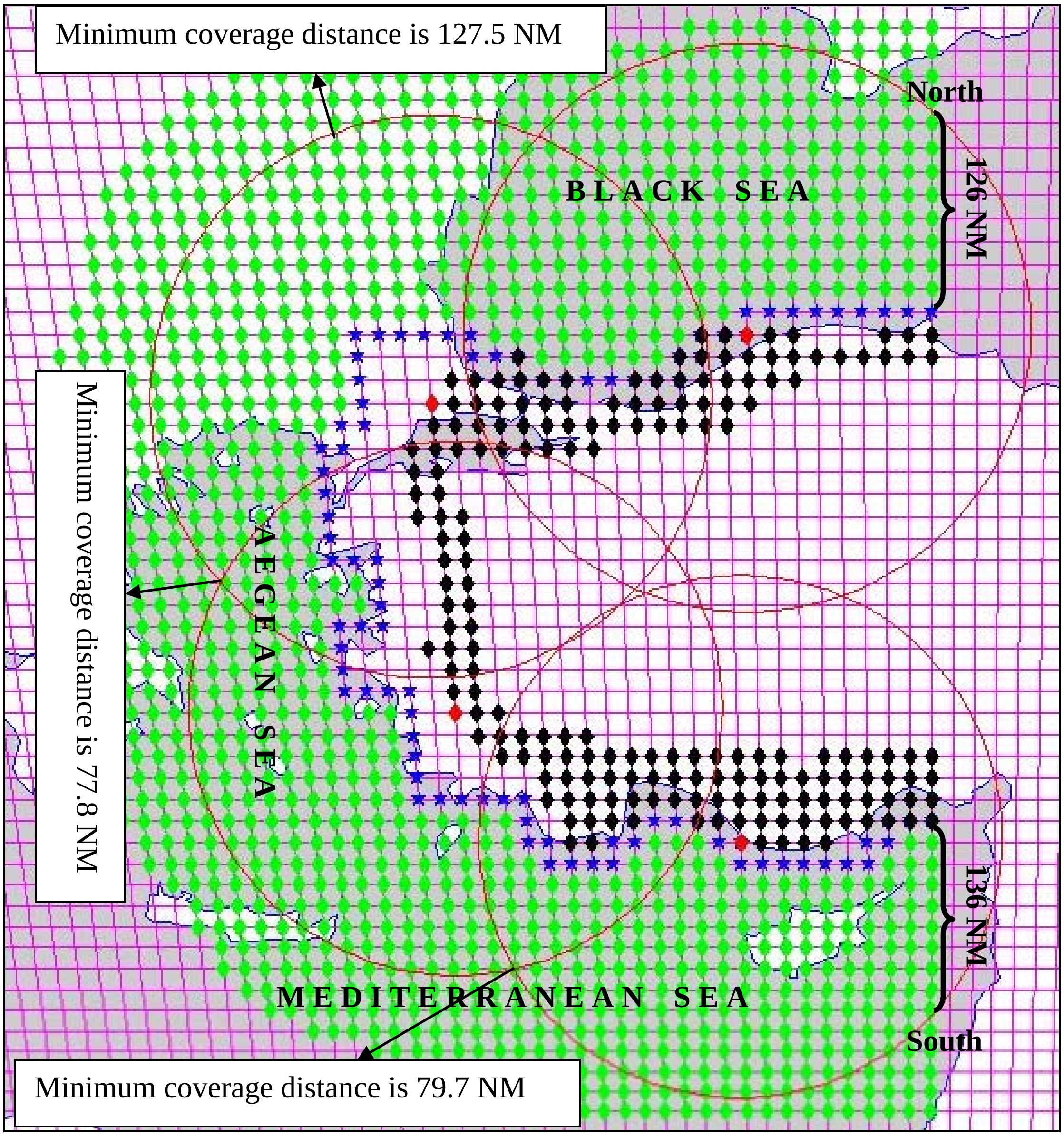


Figure 14. Initial solution of western scenario (30% risk)

In this scenario, there are 186 COPs and 1159 demand points after the elimination process. Four AEW&C aircraft are located to COPs 21, 111, 882, 1154. Seven hundred and seventy demand points are covered so the coverage rate is 66.44%.

It can easily be seen that the desired minimum coverage ranges on the Aegean Sea and on the Mediterranean Sea were not obtained. In order to increase the coverage ranges demand points 2817, 2993, 3741 and 4050 are forced to be covered by the aircraft. The aircraft are relocated to COPs 19, 270, 882 and 1130. The result of relocation is shown on Figure 15.

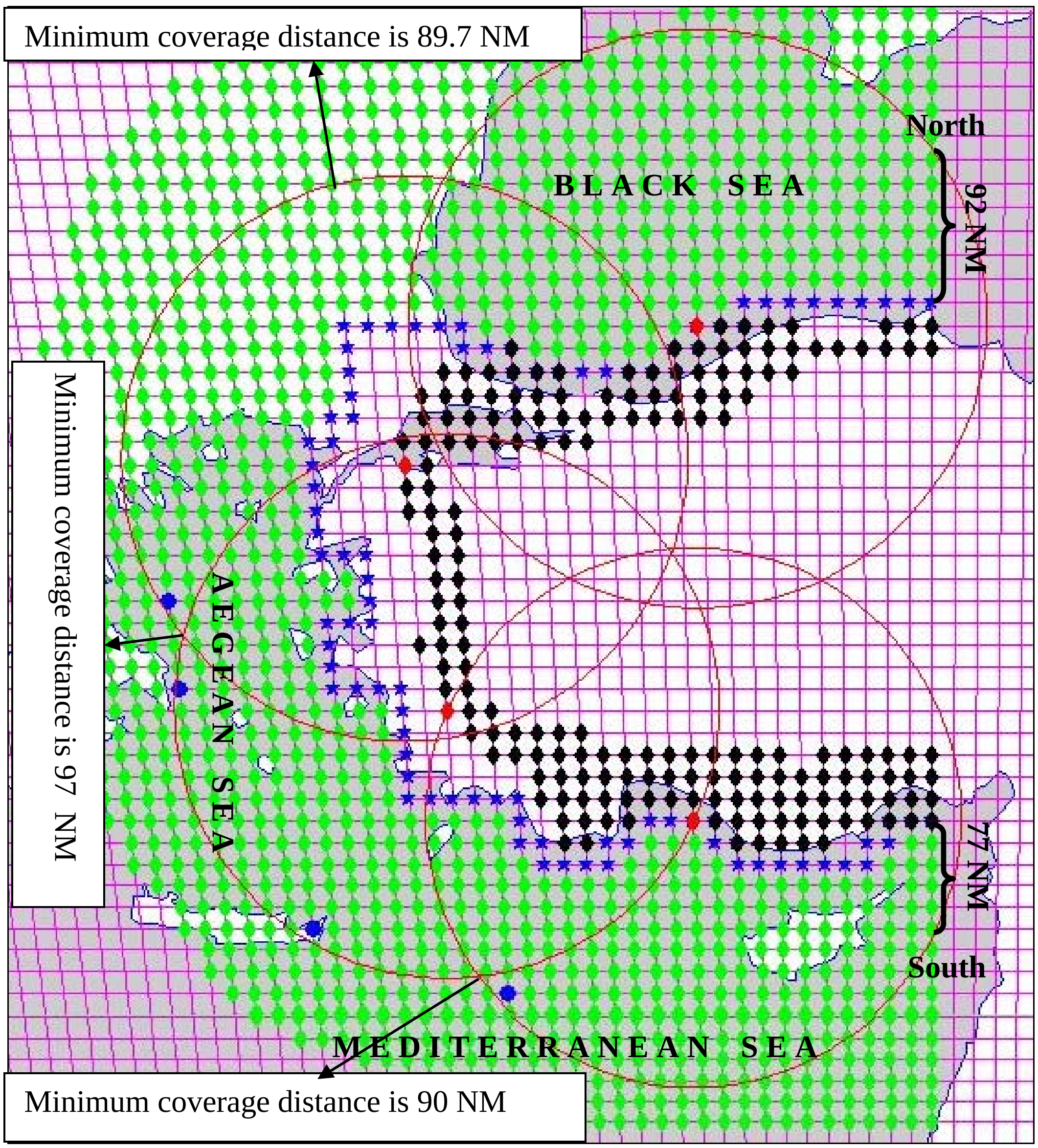


Figure 15. Solution of Western Scenario after Relocation (30% Risk)

After the relocation, 725 demand points are covered. While the coverage rate decreased to 62.55%, the coverage minimum coverage distance on the Aegean Sea increased to 97 NM, on the Mediterranean Sea to 90 NM. The minimum coverage distance on the north west part of the country decreased to 89.7 NM. The coverage distance on the north decreased to 92NM and on the south to 77 NM.

Blue dots, on Figure 15, show the demand points that are forced to be covered by the aircraft.

4.2.2 Results and Analysis of Western Scenario (20% Risk)

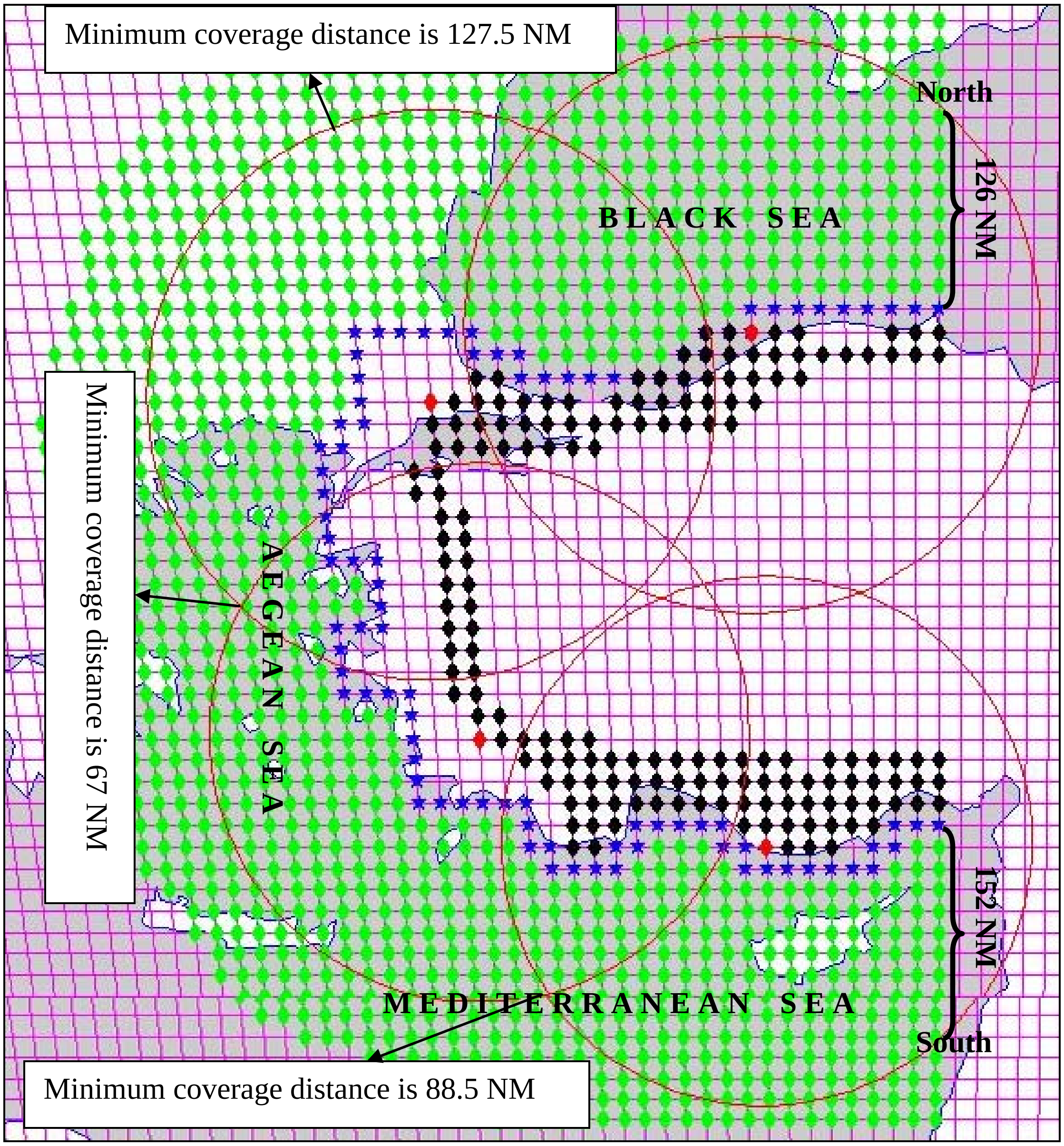


Figure 16. Initial Solution of western scenario (20% risk)

In this scenario, there are 168 COPs and 1159 demand points after the elimination process. Four AEW&C aircraft are located at COPs 21, 111, 938 and 1155. Seven hundred and sixty three demand points are covered and the coverage rate is 65.83%.

Since the minimum coverage distance was not obtained on the Aegean Sea, demand points 2863 and 3741 were forced to be covered to increase the minimum distance.

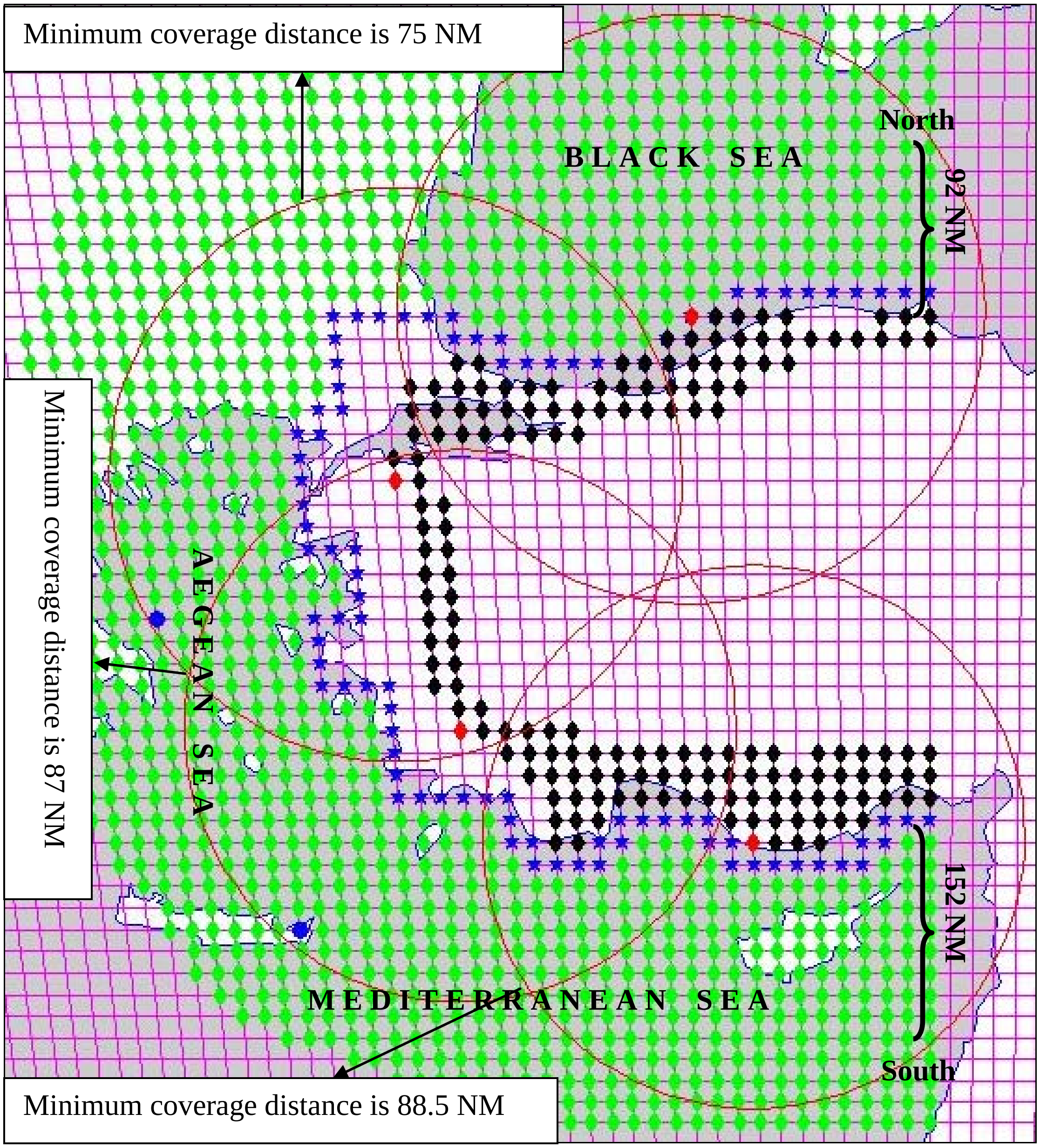


Figure 17. Solution of Western Scenario after Relocation (20% Risk)

After the relocation, 732 demand points are covered. The aircraft are located to COPs 19, 324, 938 and 1155. While the coverage rate decreased to 63.16%, the coverage minimum coverage distance on the Aegean Sea increased to 87 NM. The minimum

coverage distance in the north west part of the country decreased to 75 NM. The coverage distance in the north decreased to 92NM.

Since the coverage gain was less than the loss of the coverage, the aircraft on the south, was not relocated.

4.2.3 Results and Analysis of Western Scenario (10% Risk)

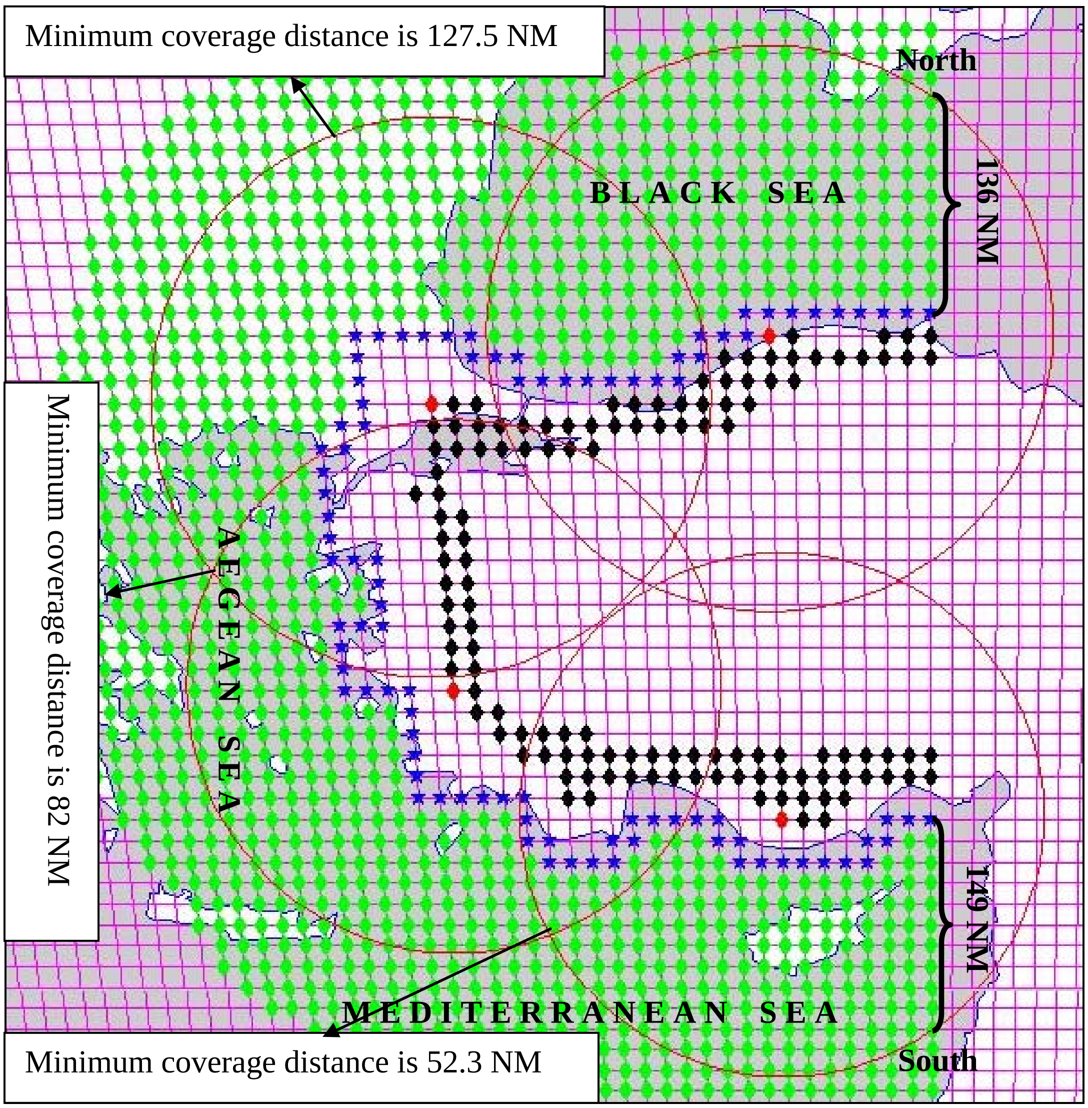


Figure 18. Initial Solution of western scenario (10% risk)

In this scenario, there are 124 COPs and 1159 demand points after the elimination process. Aircraft are located to the COPs 22, 111, 828 and 1134. Seven hundred and thirty one Demand points are covered so the coverage rate is 63.07%. Since the desired minimum coverage ranges on the Aegean Sea and the Mediterranean Sea were not obtained, demand points 1631, 2863, 3037, 4052 and 3741 were forced to be covered by the aircraft. The result of relocation is in Figure 19.

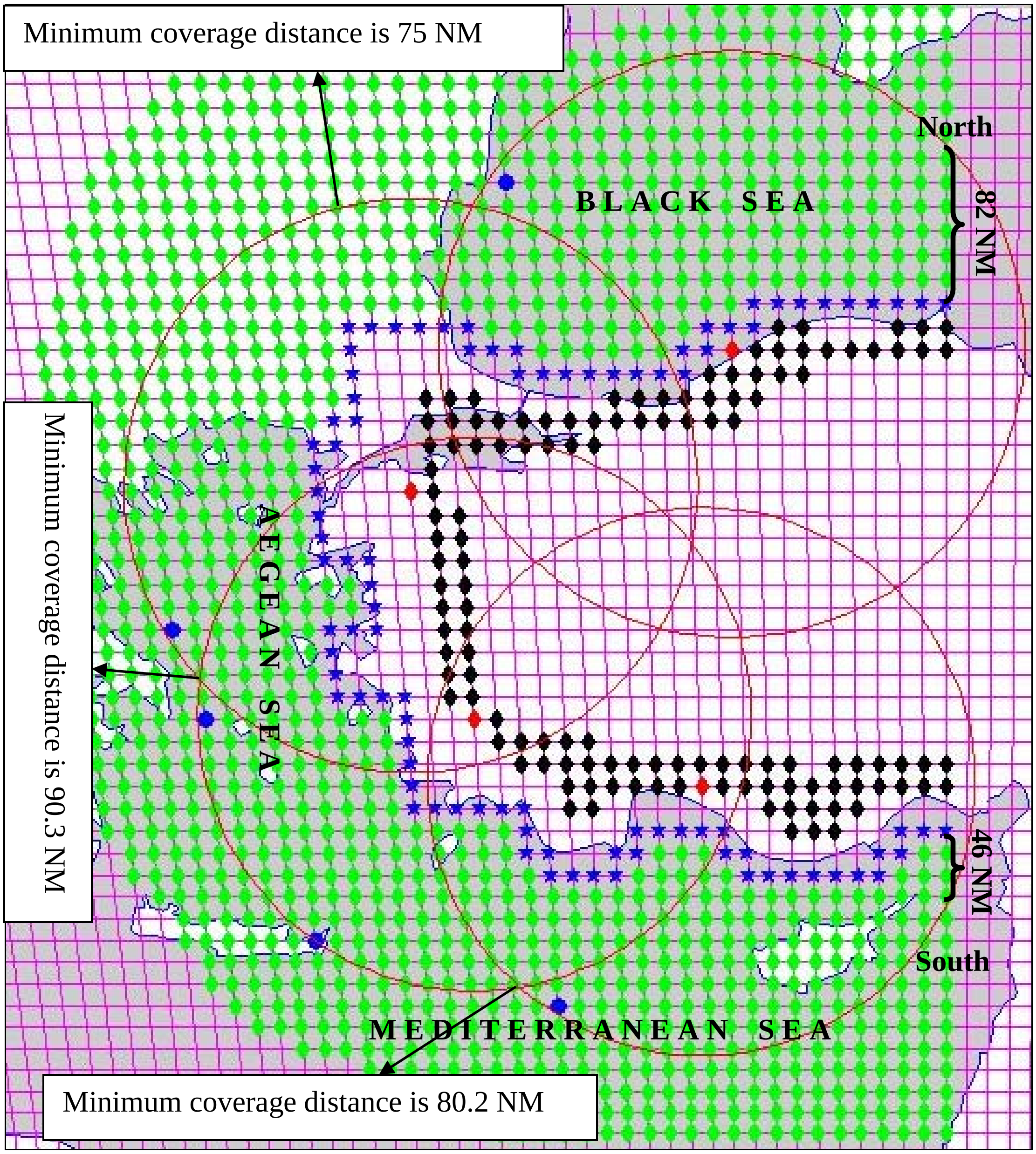


Figure 19. Solution of Western Scenario after Relocation (10% Risk)

After the relocation process, 635 demand points were covered. Aircraft are relocated to COPs 44, 324, 883 and 1056. The coverage rate decreased to 54.79%. Minimum coverage distances increased to 90.27 NM on the Aegean Sea, to 80.15 NM on the Mediterranean Sea. Minimum coverage distance on the north west part of the country

was decreased to 75 NM. As seen in the Figure 19, the minimum distance on the south decreased to approximately 46 NM. The minimum distance on the Mediterranean Sea was obtained only by compromising the distance on the south. The minimum distance on the north was decreased to 82 NM.

4.2.4 Results and Analysis of Western Scenario (No Risk)

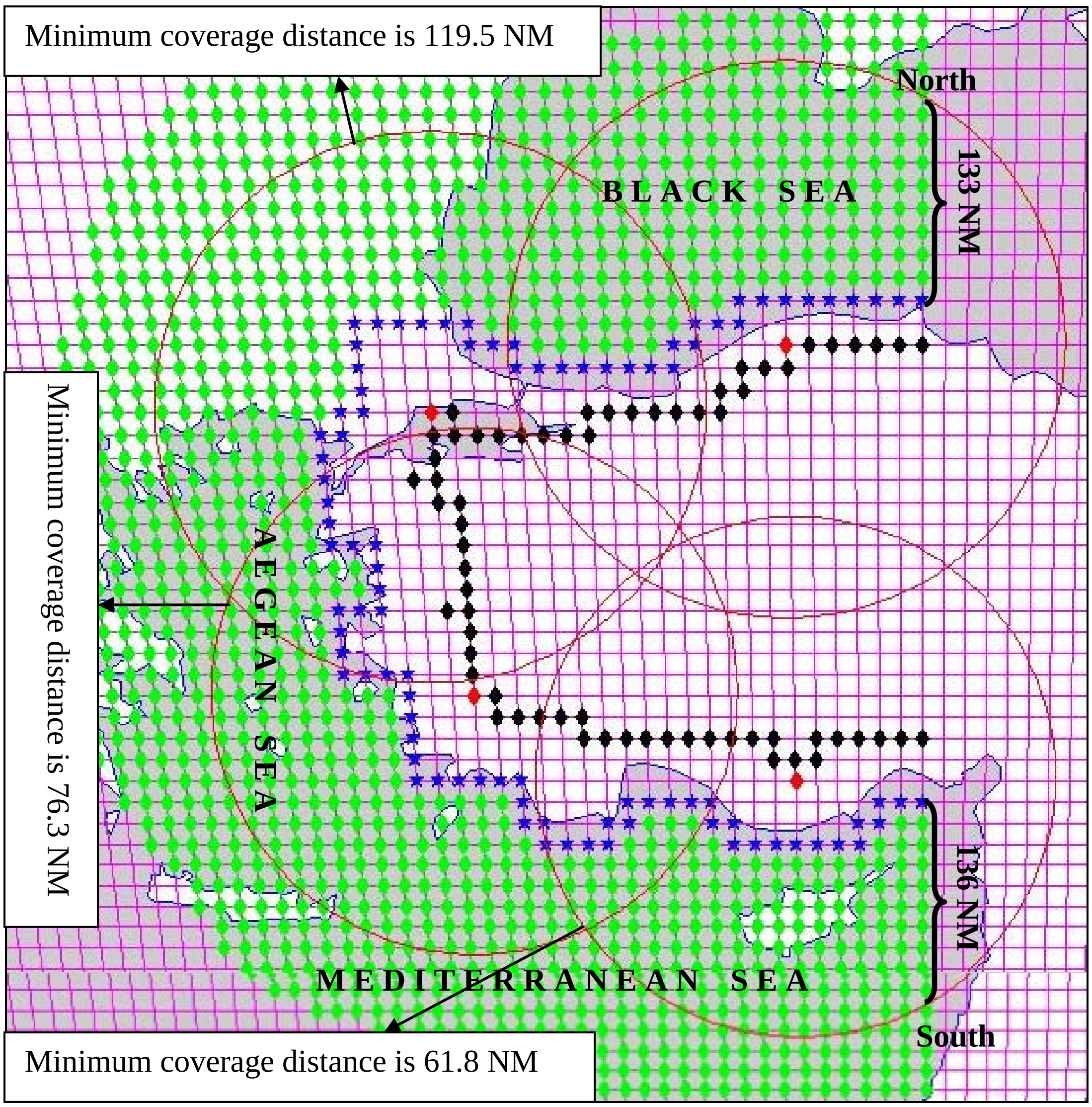


Figure 20. Initial Solution of Western Scenario (No Risk)

In this scenario, there are 71 COPs and 1159 demand points after the elimination process. Aircraft are located to COPs 47, 163, 883 and 1103. 673 demand points are covered so the coverage rate is 58.07%. Since minimum coverage distances on the Aegean Sea and the Mediterranean Sea were not obtained, demand points 2863, 3037, 3952 and 3473 were forced to be covered by the aircraft. The result of relocation is shown in Figure 21.

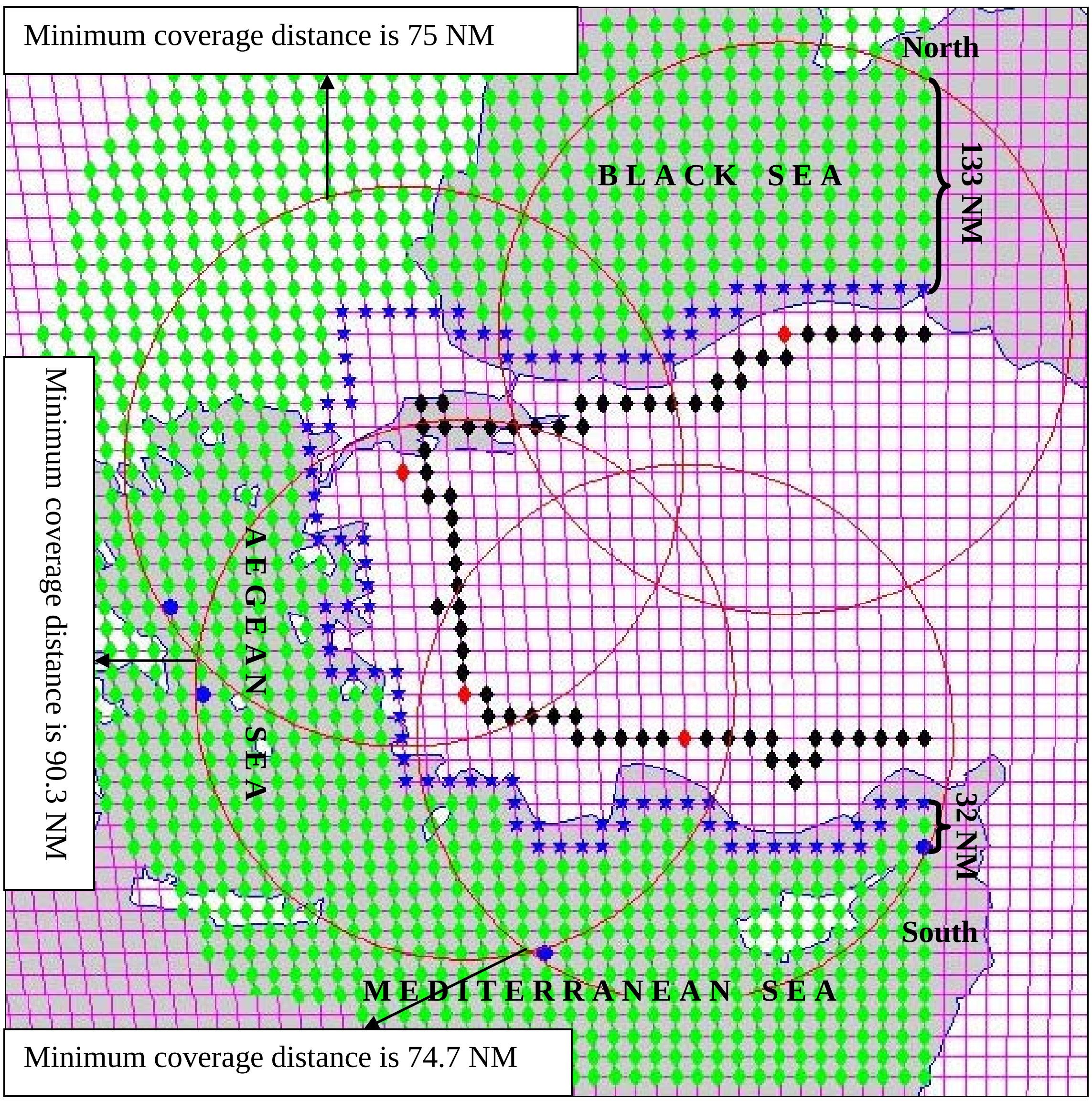


Figure 21. Solution of Western Scenario after Relocation (No Risk)

After the relocation process, 606 demand points are covered. The coverage rate was decreased to 42.29%. The aircraft were relocated to COPs 47, 324, 883 and 1003. Minimum coverage distance on the Aegean Sea increased to 90.27. Minimum coverage distance on the Mediterranean Sea increased to 74.7. If the aircraft on the south is wanted to be relocated closer to west, the coverage distance on the South Cyprus is decreased. Because of this 74.7 NM coverage distance was accepted for minimum coverage distance on the Mediterranean Sea. Minimum coverage distance on the north west part of the country decreased to 75 NM. The coverage distance on the south has not changed. A summary of the all results is shown in Table 4.

Table 4. Western Scenario Results Report

Region	Risk	AEW &C	Coverage Rate			Min Range from Borders (NM)		
			Relocation		Difference	Relocation		Difference
			No	Yes		No	Yes	
North	30%	4	66.44%	62.55%	-3.89%	126	92	-34
North West						127.5	89.7	-28.8
Aegean						67	97	30
Mediter.						80	90	10
South						136	77	-69
North	20%	4	65.83%	63.16%	-2.67%	126	92	-34
North West						127.5	75	-52.5
Aegean						67	87	20
Mediter.						88	88.5	0.5
South						152	152	0
North	10%	4	63.07%	50.82%	-8.28	136	82	-54
North West						127.5	75	-52.5
Aegean						82.5	90.3	7.8
Mediter.						52.3	80.2	27.9
South						149	46	-103
North	0%	4	58.07%	52.29%	-5.78	133	133	0
North West						119.5	75	-44.5
Aegean						76.3	90.3	14
Mediter.						61.8	74.7	12.9
South						136	32	-104

Table 4 shows the results of the western scenario. The coverage rates decrease gradually while the acceptable risk decreases, since low risk COPs are located on the inner sides of the country. When the after relocation results are compared, while the minimum coverage distance is 97 NM for the 30% risk scenario on the Aegean Sea, this range is decreasing to 87 NM for 20% risk scenario. Since the distance increase can only be obtained by relocating one of the aircraft to COP 324 and one aircraft to COP 883, the minimum coverage distance on the Aegean Sea for the 10% risk scenario is greater than the 20% scenario's minimum coverage distance on the Aegean Sea. The minimum coverage distance on the Aegean Sea for the zero risk scenario, is also greater than the minimum coverage distance on the Aegean Sea for 20% risk scenario for the same reason. The minimum coverage distances on the north part of the country are 75 NM for 20%, 10% and zero risk scenarios. While the minimum coverage distance on the Mediterranean Sea is 90 NM for the 30% risk scenario, with a low decrease, this distance is 88.5 NM for 20%. The minimum distance on the Mediterranean Sea is 80.2 NM for 10% risk scenario. This distance decreases to 74.7 NM for no risk scenario and was accepted since it is close to 75 NM.

When the coverage rates of 30% risk and 20% risk scenarios are compared, the coverage rate of 20% scenario is greater than the 30% risk scenario. Since no more improvement was obtained, the aircraft on the north and on the north west were relocated but the aircraft on the south was not relocated. This caused the coverage rate of the 20% risk scenario to be greater than the 30% risk scenario's coverage rate. On the other hand the coverage rates of the 10% and no risk scenarios decrease.

The coverage distance on the south decreased to 46 NM to obtain the minimum coverage distance the Mediterranean Sea for 10% risk. This distance decreased to 32 NM for the same reason. Nevertheless, only 74.7 NM coverage distance was obtained on the Mediterranean Sea.

4.2.5 Conclusion

The commander has to choose the acceptable coverage according to the risk that he accepts. Location of more than four aircraft may be taken under consideration if there is no budget constraint. On the other hand location of more aircraft in a narrow area can cause additional risk. Because of this, more than four aircraft was not used. According to the results shown in Table 4, 20% Risk can be taken under consideration, since risk is lower and the coverage rate is not much lower than the 30% risk scenario's coverage rate. The minimum coverage distances on the regions were obtained. Satisfactory coverage could not be obtained with three aircraft or less. Figure 22 shows the proof that less than four aircraft would not be enough.

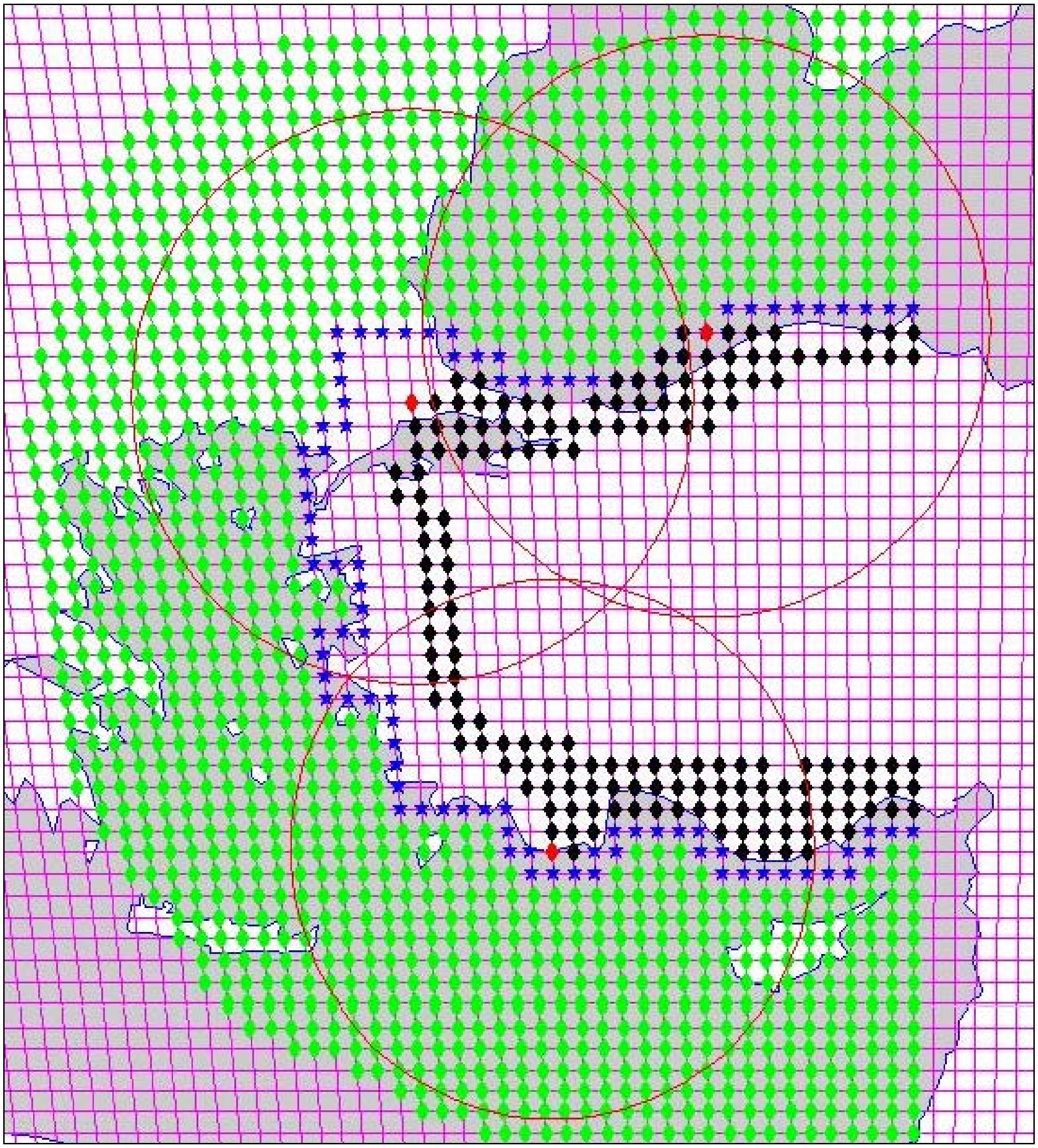


Figure 22. Solution of Western Scenario (Three aircraft 20% Risk)

4.3 Eastern Scenario

The threat from the east includes the east and south east and north east parts of Turkey. The south and the north part of the country are also taken under consideration. This is a wide area and the longest range of possible threat that can affect AEW&C aircraft is 91 NM. In this manner, the air space AEW&C aircraft use is also limited. The environmental conditions are same as those in the west part of Turkey.

The eastern scenario has 1170 demand points and 223 COPs, before the COP elimination process. The cover radius used is 185 NM. Four AEW&C aircraft are available. Each COP is located approximately 15 NM apart. Initial A matrix is a 1171 by 1393 matrix, before the elimination process. Six adversary SAM sites and 9 adversary airbases are located close to Turkey's borders to portray a realistic scenario. All the SAM sites are S-300 SAM systems. Since the real number of the SAM systems is unknown, the number of SAM sites is chosen to illustrate their modeling. Coordinates and the numbers can be changed by user. It is assumed that the commander accepts the risk up to 30%. It can easily be observed that the coverage distance in some regions is not far enough. In order to increase the minimum coverage distances, the aircraft are relocated and changes to the coverage rates and distances are analyzed.

The same relocation process used for the western scenario is applied to increase the minimum coverage distances. In the eastern scenario, first priority is given to the east part of the country. Then minimum coverage distance on the south east part of the country is increased. The last priority is given to the north east part of the country. The minimum coverage distance desired on the north east is 75 NM. 85 NM minimum

coverage distance is desired on the east and minimum 80 NM coverage distance is desired on the south east. While these distances are obtained, the distances on the north and south are kept at a minimum of 70NM. If the minimum coverage distances in the north east, east and south east can only be obtained by decreasing the distances on north and south below 70 NM, this is accepted. 30% risk and 20% risk scenarios have the same results. Results and analyses are shown on the next pages.

4.3.1 Results and Analysis of Eastern Scenario (30% and 20% Risk)

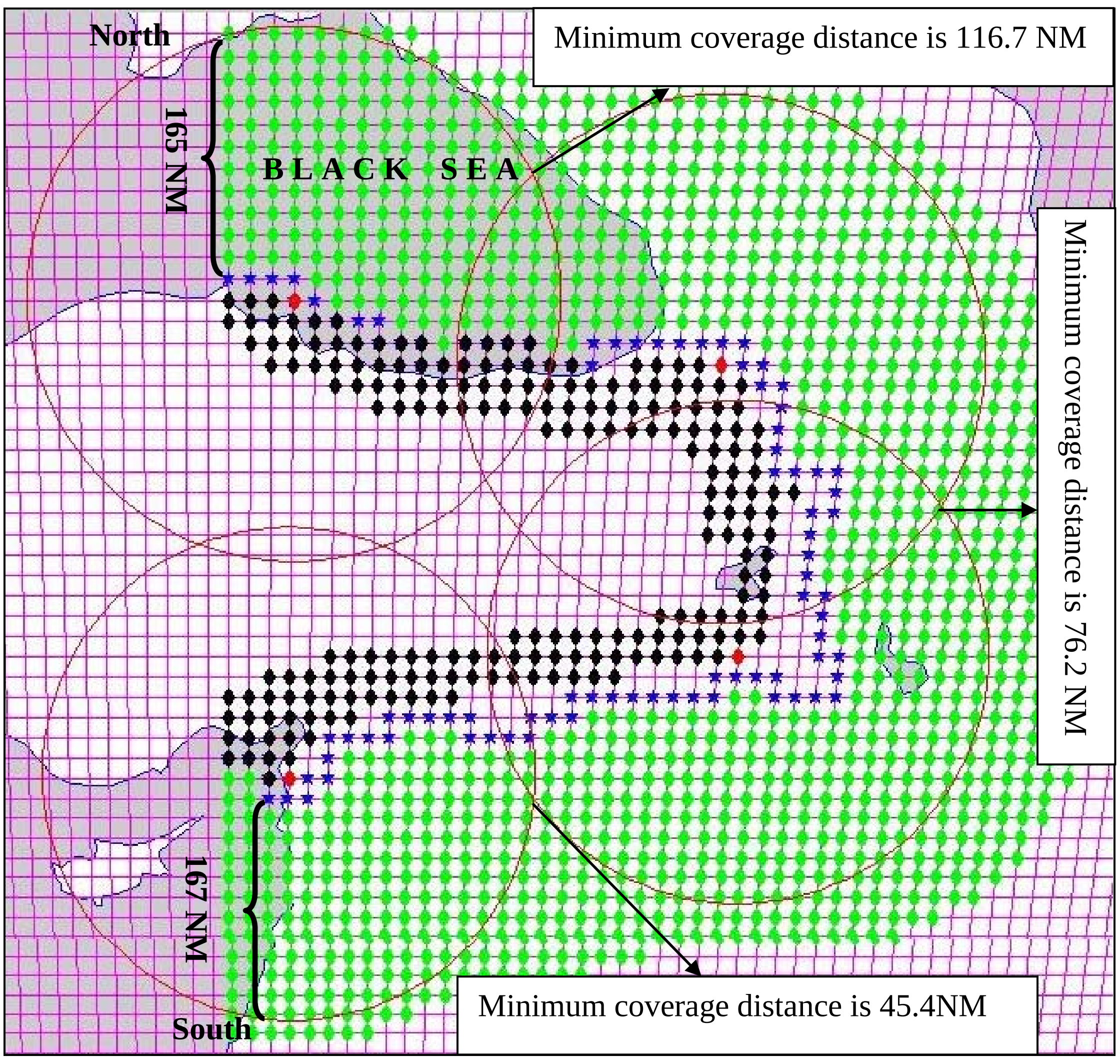


Figure 23. Initial Solution of Eastern Scenario (30% and 2%0 Risk)

In the 30% risk scenario, there are 206 COPs and 1170 demand points. In the 20% risk scenario, there are 197 COPs. Aircraft are located to the COPs 32, 156, 929 and 1163. Eight hundred and thirty six demand points are covered so the coverage rate is 71.45%. Since the desired minimum coverage distances in the east and south east were not obtained, demand points 1449, 1473, 1564, 2655, 2741, 3688 and 3870 are forced to be covered. The result of the relocation is shown in Figure 24.

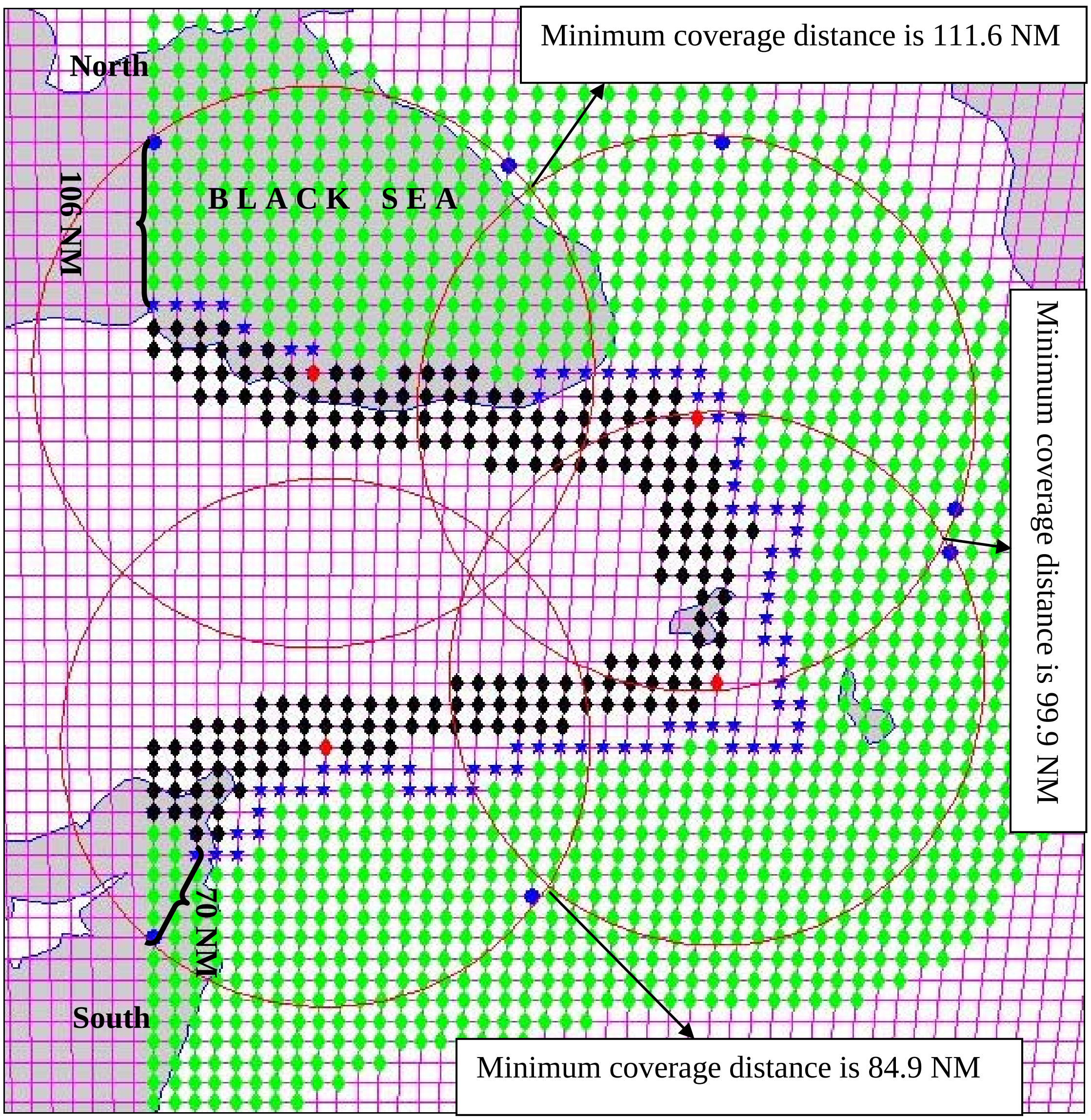


Figure 24. Solution of Eastern Scenario after Relocation (30% and 20% Risk)

After the relocation, the coverage rate decreased to 66.58%. seven hundred and seventy nine demand points are covered. The aircrafts are relocated to COPs 93, 209, 876 and 1022. Although the decrease of the coverage rate and the number of demand point covered, the minimum coverage distances on the south east increased from 45.4 NM to 84.9, and in the east from 76.2 NM to 99.9 NM. The coverage distance in the north, decreased from 116.7 NM to 111.6 NM. While the coverage distance in the south decreased to 70 NM, the coverage distance in the north decreased to 106 NM.

4.3.2 Results and Analysis of Eastern Scenario (10% Risk)

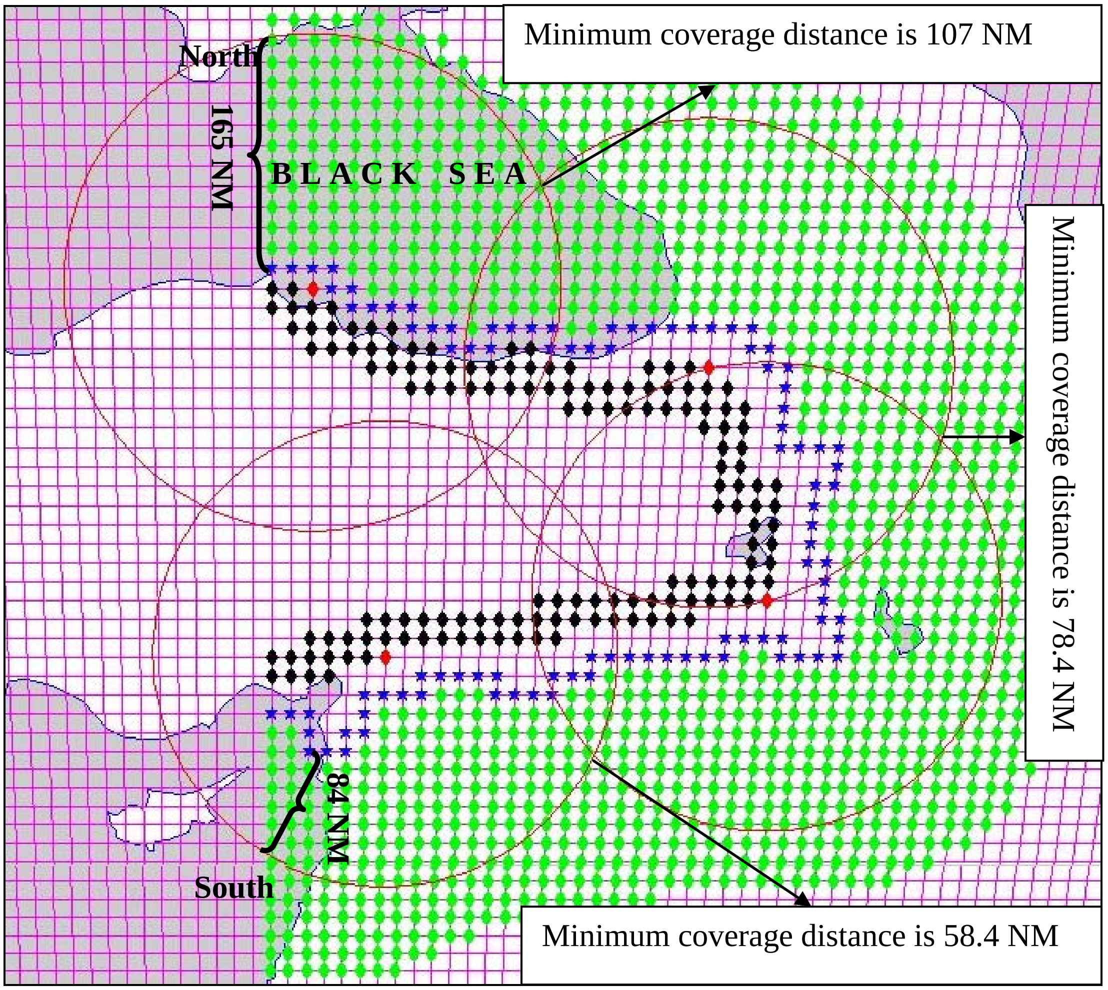


Figure 25. Initial Solution of Eastern Scenario (10% Risk)

In this scenario, there are 168 COPs and 1170 demand points. Aircraft are located to COPs 31, 207, 876 and 1020. Seven hundred and forty eight demand points are covered. The coverage rate is 63.93%. Since the minimum desired coverage distances were not obtained in the east and south east, demand points 1649, 1665, 2654, 3506, 3670 and 3688 are forced to be covered by the aircraft. The result of relocation is shown in Figure 26.

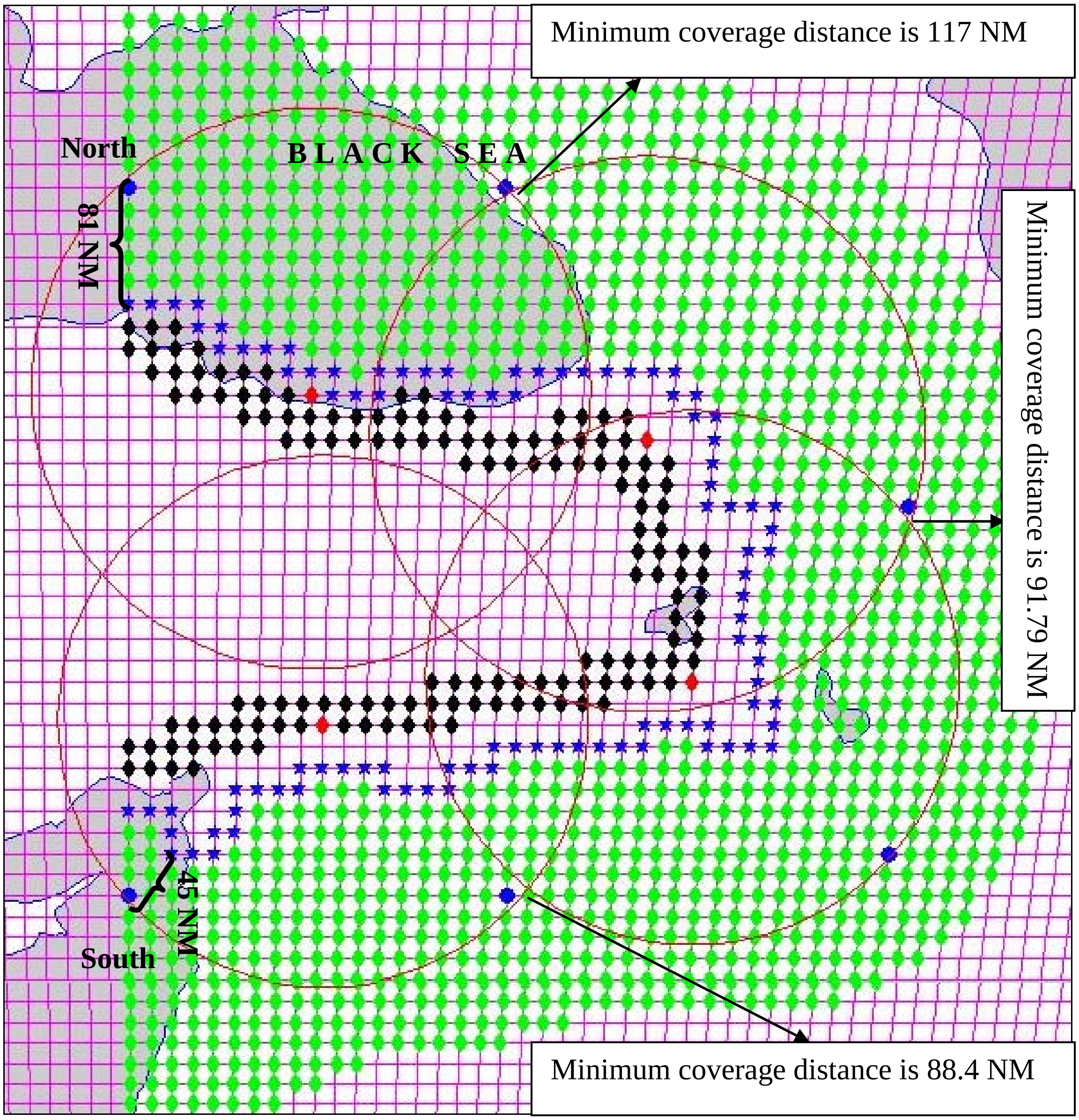


Figure 26. Solution of Eastern Scenario after Relocation (10% Risk)

After the relocation process, the coverage rate decreased to 60.77 % and the number of demand points covered decreased to 711. The aircraft are relocated to COPs 141, 262, 876 and 968. Although the decrease, the minimum coverage range increased from 78.4 NM to 91.8 NM in the east and the minimum coverage range increased from 58.4 NM to 88.4 NM in the south. The minimum coverage range increased from 107 NM

to 117 NM in the north east. The coverage distance in the north decreased to 81 NM. The coverage distance in the south is decreased to 45 NM. The coverage distance is accepted to increase the minimum distance in the south east.

4.3.3 Results and Analysis of Eastern Scenario (No Risk)

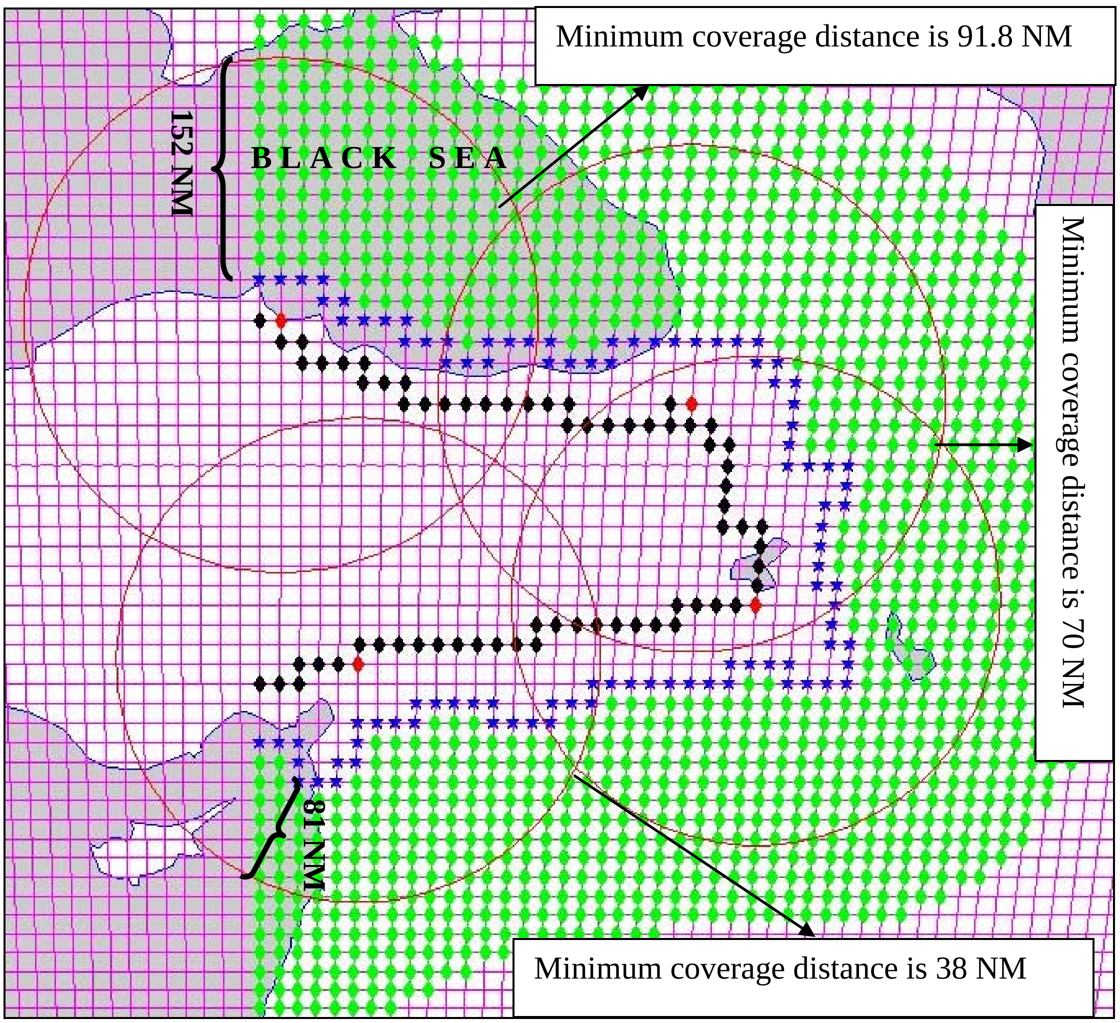


Figure 27. Initial Solution of Eastern Scenario (No Risk)

In this scenario, there are 71 COPs and 1170 demand points. Six hundred and thirty nine demand points are covered and the coverage rate is 54.62%. Aircraft are located at COPs, 54, 260, 818 and 964. The desired minimum coverage distances on east

and south east were not obtained. Because of this demand points 1649, 1764, 2610, 3419, 3570 and 3687 are forced to be covered by the aircraft. The result of the relocation is shown in Figure 27.

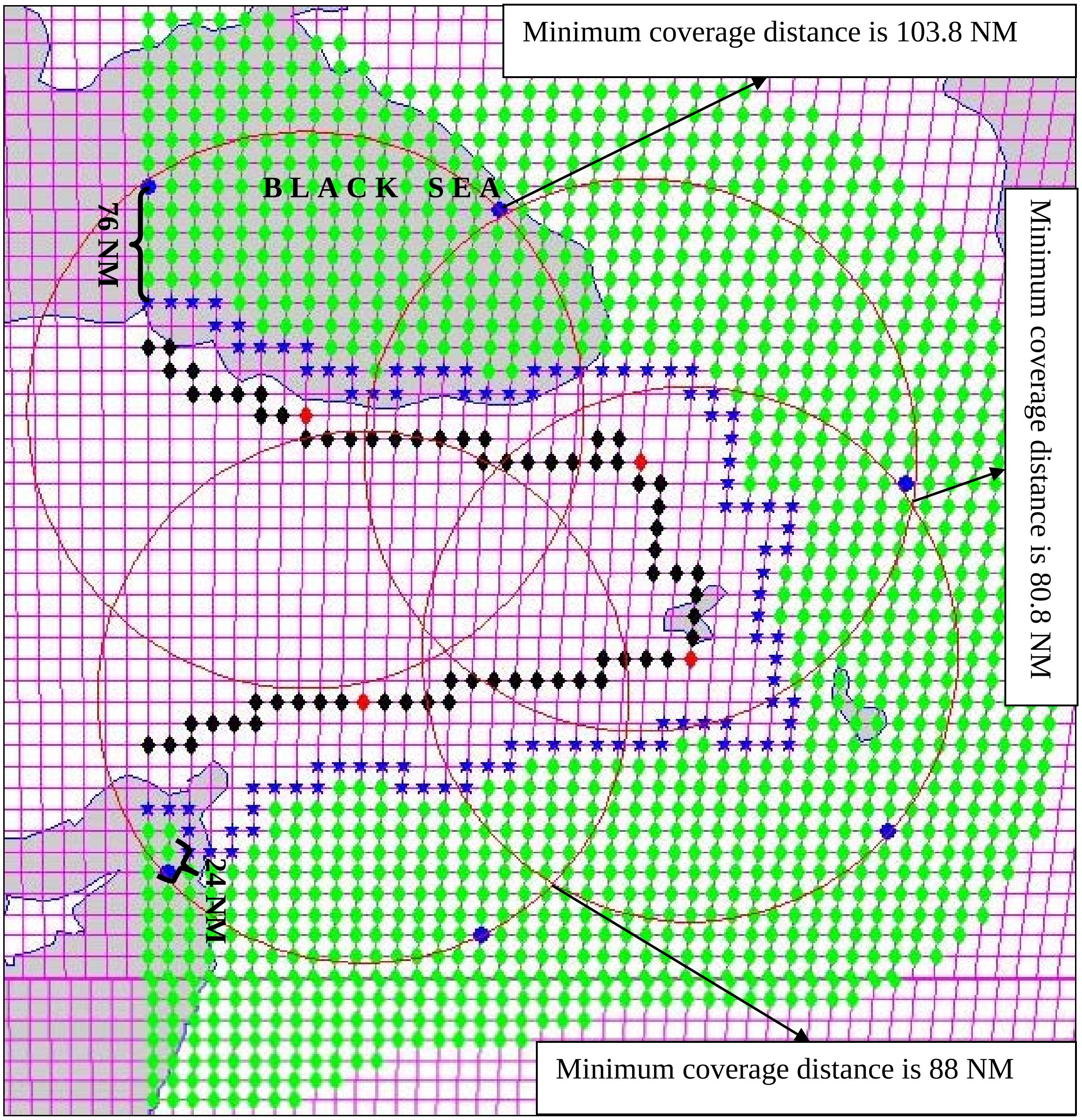


Figure 28. Solution of Eastern Scenario after Relocation (No Risk)

After the relocation of the aircraft, 611 demand points are covered. The coverage rate reduced to 52.05%. The aircraft are relocated to COPs 192, 315, 818 and 913.

Although the coverage rate decreased, the minimum coverage range increased from 70 NM to 80.8 NM in the east and the minimum coverage range increased from 38 NM to 88 NM in the south. 80.8 NM minimum coverage distance was accepted in the east since the aircraft would have been relocated closer to each other in order to increase the minimum coverage distance. Minimum coverage distance was increased from 91.8 NM to 103.8 NM in the north east. While the coverage in the north decreased to 76 NM, it is decreased to 24 NM on the south.

The results of eastern scenario are summarized in Table 5.

Table 5. Eastern Scenario Results Report

Region	Risk	AEW &C	Coverage Rate: Relocation No	Coverage Rate: Relocation Yes	Coverage Rate: Difference	Min Range from Borders (NM): Relocation No	Min Range from Borders (NM): Relocation Yes	Min Range from Borders (NM): Difference
North	30% & 20%	4	71.45%	66.58%	-4.87%	165	106	-59
North East						116.7	111.7	14.5
East						76.2	99.9	23.7
South East						45.4	84.9	39.5
South						167	70	-97
North	10%	4	63.93%	60.77%	-2.3%	165	81	-84
North East						107	117	10
East						78.4	91.8	13.4
South East						58.4	88.4	30
South						84	45	-39
North	0%	4	54.62%	52.05%	-2.57%	152	76	-76
North East						91.8	103.8	12
East						70	80.8	10.8
South East						38	88	50
South						81	24	-57

Table 5 shows the results of the eastern scenario. The coverage rates decreases gradually while the risk decreases, since low risk COPs are located on the inner sides of the country. Minimum coverage distance becomes 99.9 NM on the east, 84.9 on the south east and 111.7NM in the north east, after the relocation, for 30% Risk and 20% Risk

Scenarios. The minimum cover distance becomes 91.8 NM in the east, 88.4 NM in the south east and 117 NM on the north east for 10% Risk Scenario. For no risk scenario, 80.8 NM minimum distance in the east was accepted after the relocation process, since in order to increase the minimum distance the two aircraft on the north east and south east had to be relocated very close to each other. Close location of the aircrafts may cause additional risk. The minimum coverage distance in the south east is 88 NM and 103.8 NM in the north east after relocation process for no risk scenario.

4.3.4 Conclusion

There are multiple choices in this scenario. The commander has to make the decision according to the risk he is willing to accept. Location of more than four aircraft may be taken under consideration if there is no budget constraint. On the other hand, location of more aircraft in a narrow area can cause additional risk. According to the results in Table 5, 20% risk can be taken under consideration, since the risk is low and minimum cover distance and coverage rate is the same as that of 30% risk. The minimum coverage distances in the regions were obtained. Desired minimum coverage distances cannot be obtained using less than four aircraft. Figure 28 shows that less than four aircraft would not be enough.

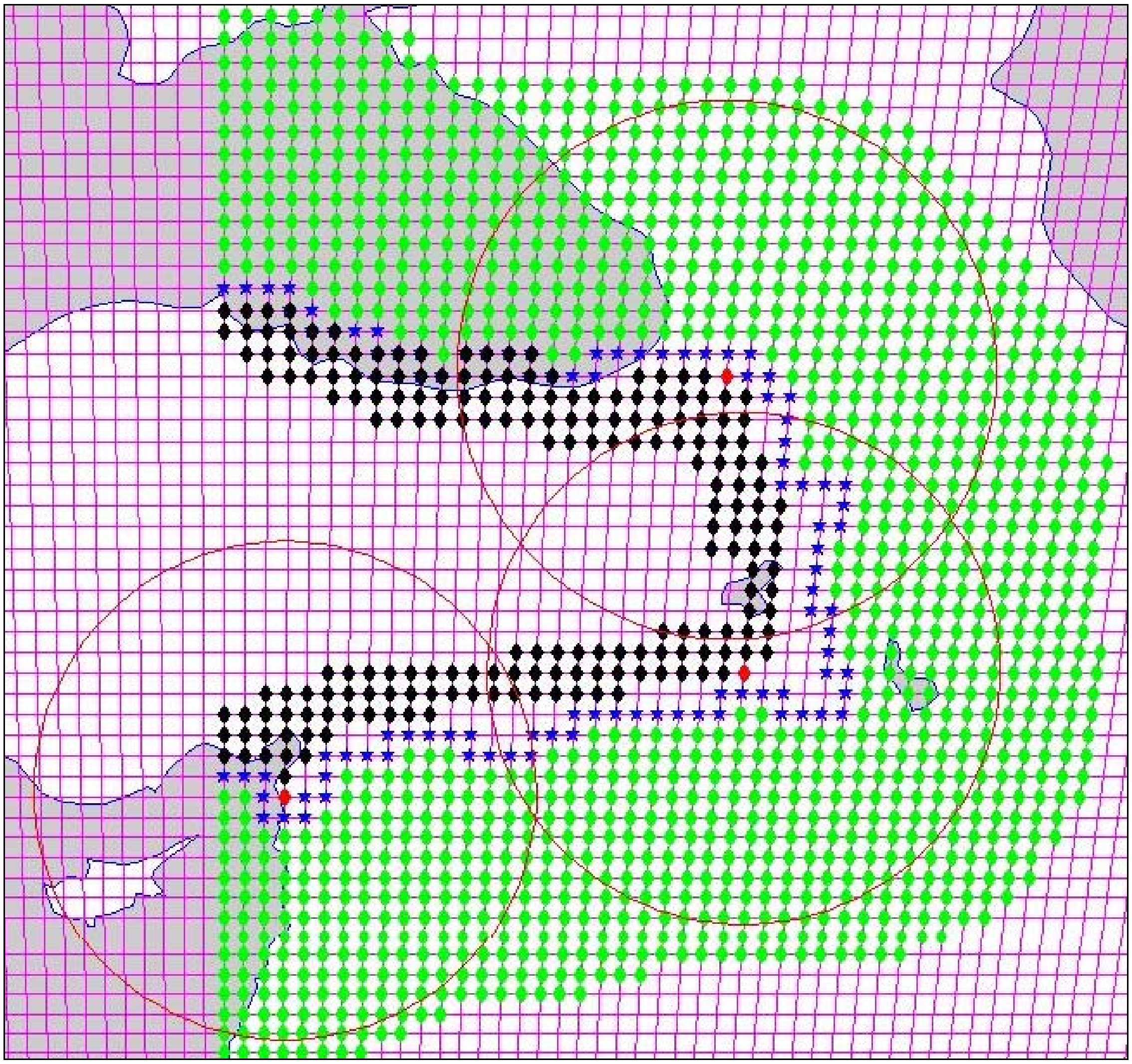


Figure 29. Solution of Eastern Scenario (Three Aircraft, 20% Risk)

4.4 Combination of the Two Scenarios

This scenario includes both scenarios covered in the previous sections. Since 20% risk scenario has been chosen for both west and east scenarios, a scenario with 20% risk was modeled for the whole country. There are 360 COPs and 2303 demand points. The A matrix is a 2034 by 2693 matrix.

Since there is a budget constraint, no more than eight aircraft are used in this research. First, the program was run with eigth aircraft without forcing the aircraft to

cover the determined demand points, then the program was run forcing the aircraft to cover the determined demand points. After this, one of the demand points which were forced to be covered by the aircraft was removed from the solution to see the change. The priorities to increase the minimum distances for the regions of the country are as follows: Aegean Sea (85 NM), Mediterranean Sea (80 NM) , the east part of the country (85 NM), the south east part of the country (80 NM), south part of the country (75 NM), north west part of the country (75 NM), north east part of the country (75 NM), north part of the country (75 NM). The results of the western and eastern scenarios for 20% risk are then combined. The program is run for seven aircraft to see the coverage rates and minimum coverage distances. Finally, a conclusion was made. Figure 30 shows the result of the initial run of the optimization program with eight aircraft.

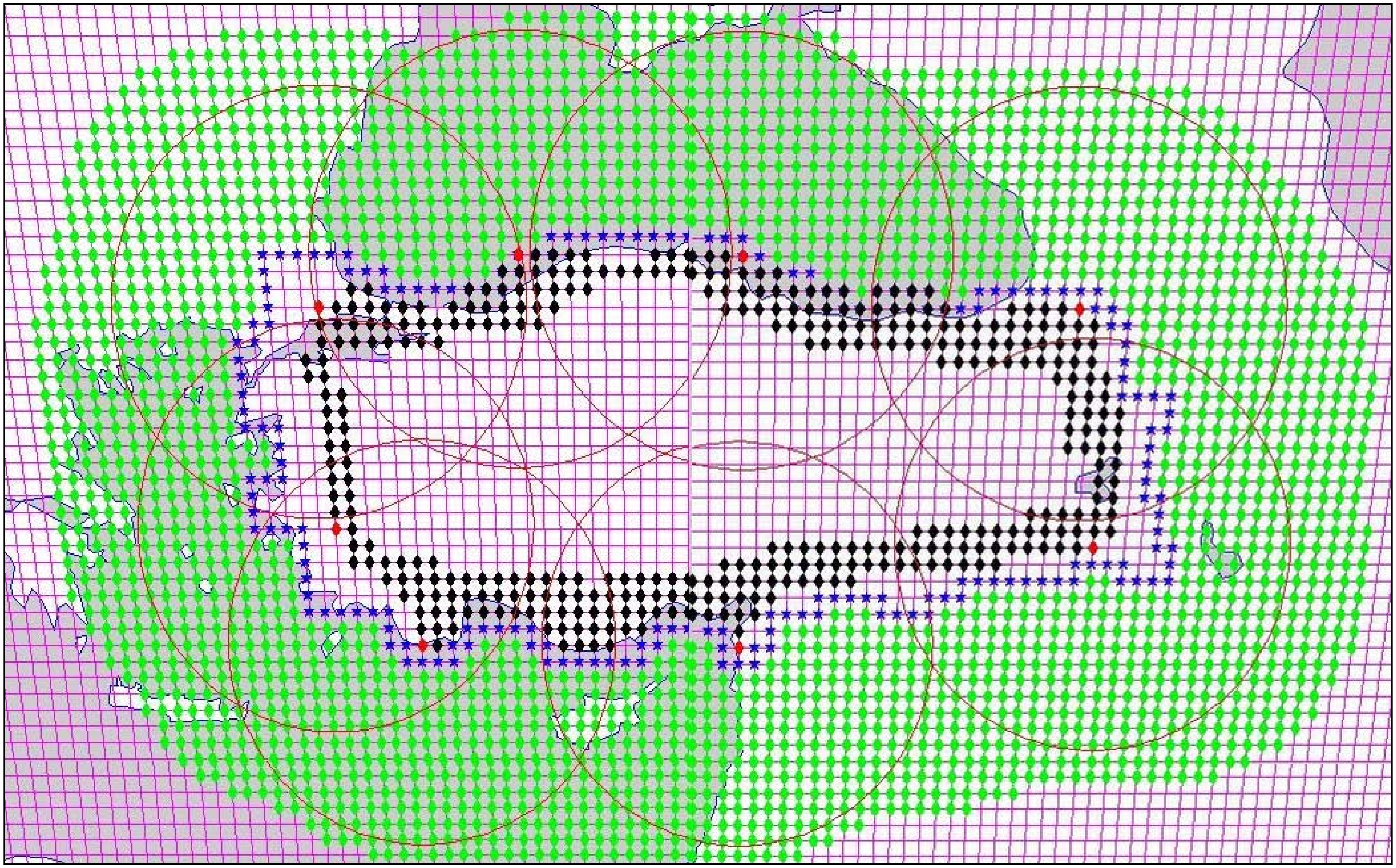


Figure 30. Initial solution with 8 eight AEW&C aircraft

According to the initail result, the coverage rate is 70.56% and 1625 demand points are covered. Aircraft are located at COPs 19, 32, 111, 156, 828, 929, 1149 and 1163. Although the minimum covering distance is 143.7 NM on the north part of the country, it is 45.47 NM on the south. The minimum desired covering distances on the Aegean Sea, in the east and south east parts of the country is not obtained. Since there is a budget constraint, no more than eight aircraft can be located. The results of the initial run is shown in Table 6.

Table 6. Result Report of The Initial Run

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	20%	8	70.56%	135.7
North				143.8
North East				116.7
East				76.2
South East				45.4
South				91
Mediterranean				109.3
Aegean				82.5

Figure 31 shows the minimum covering ranges on the respective parts of the country.

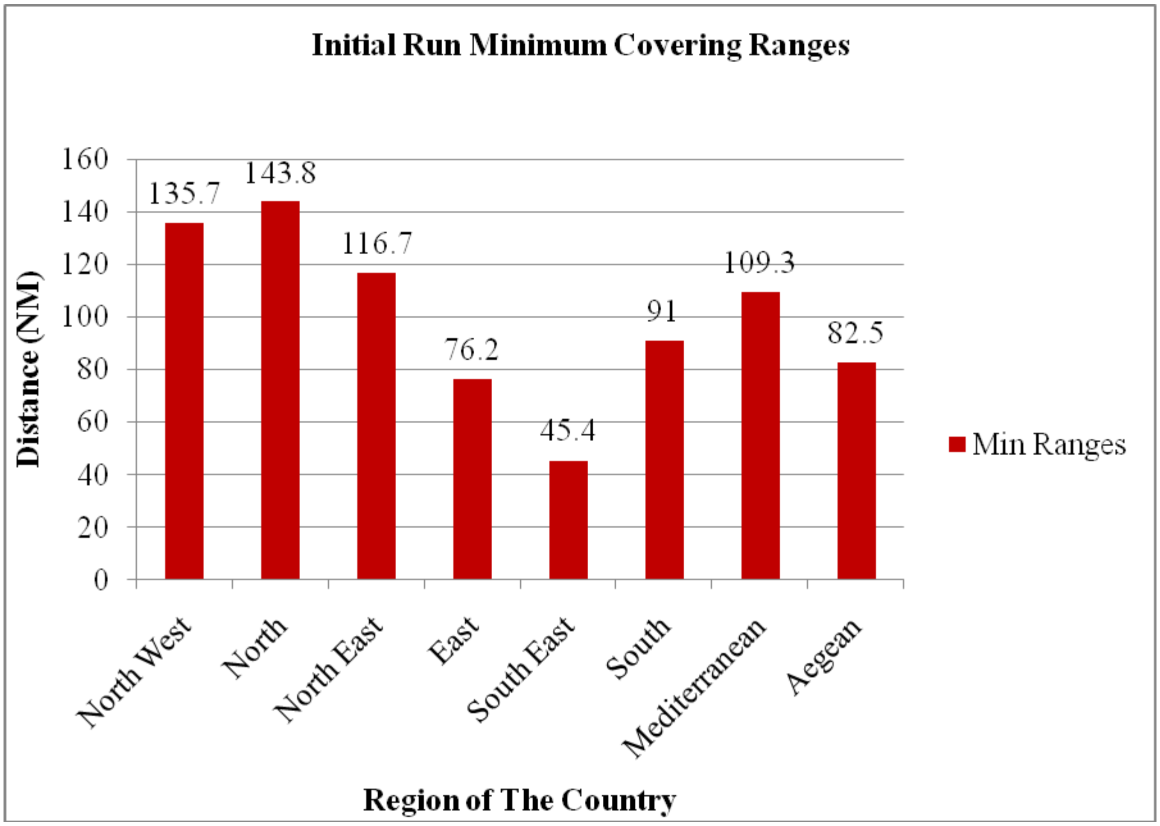


Figure 31. Minimum Covering Ranges of Initial Solution

In order to obtain the minimum desired coverage distances, aircraft are forced to cover the demand points 2655, 2863, 3506, 3741, 3985, 4073 and 4153. The relocation of the aircraft is shown in Figure 32.

After the relocation process, the aircraft are relocated to COPs 19, 32, 209, 324, 876, 938, 1022, 1155. The total coverage rate is 66.17% and 1520 demand points are covered.

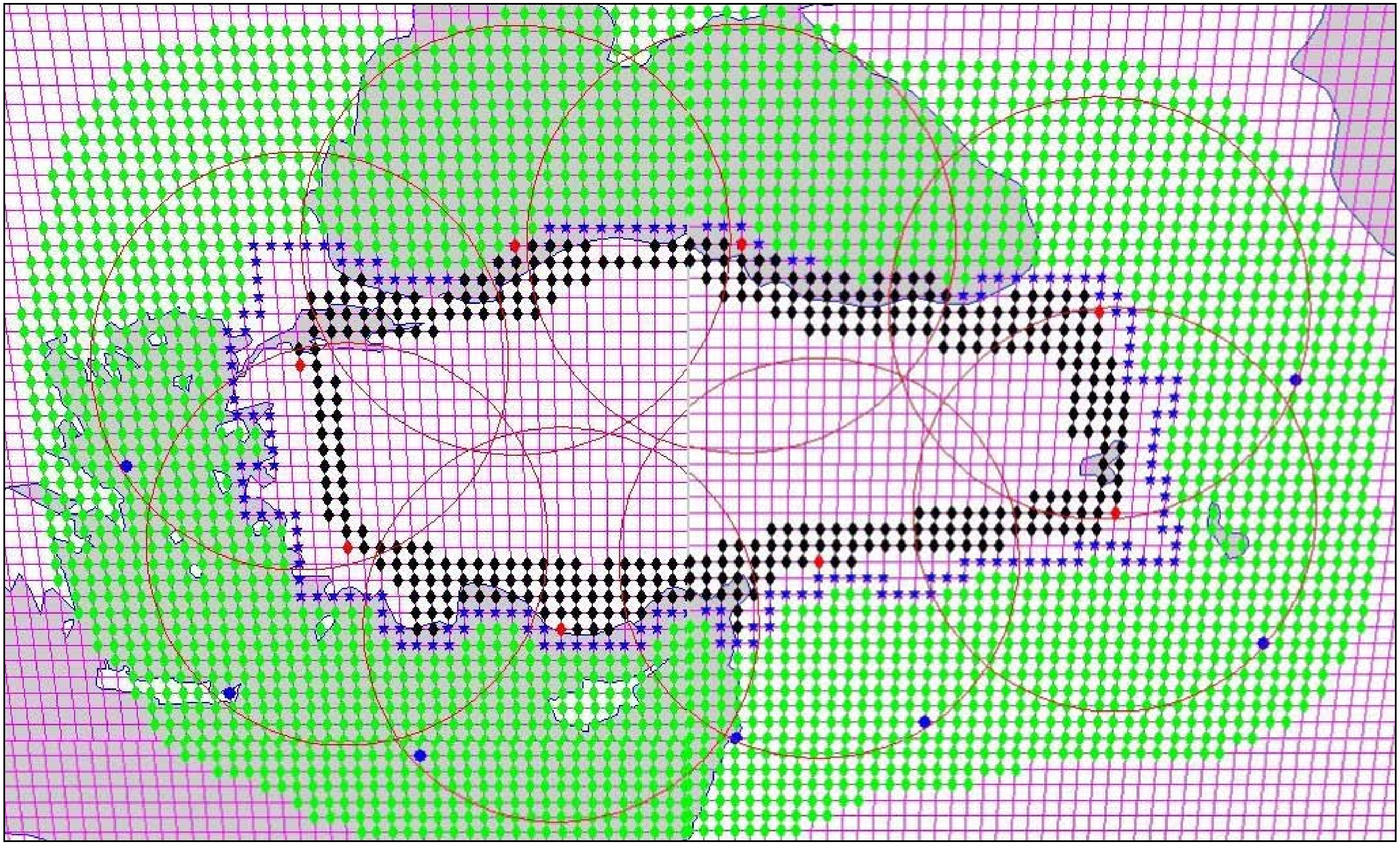


Figure 32. Solution after Relocation (Eight Aircraft)

The results of the run after the relocation process is shown in Table 7.

Table 7. Result Report of after the Relocation

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	20%	8	66.17%	75
North				143.7
North East				97
East				99.9
South East				84.9
South				87
Mediterranean				88.5
Aegean				87

Although the coverage rate decreases to 66.17%, the desired minimum covering distances are obtained. The minimum coverage range on the north is 143.7. If the aircraft at COP 19 is moved to the west, there will not be any change in the minimum coverage distance in the north west. In addition to this, the aircraft would be located very close to each other. If the aircraft is moved to east, then the minimum distance on the north east can be increased and aircraft separation is obtained. Figure 33 shows the minimum covering ranges for the respective parts of the country.

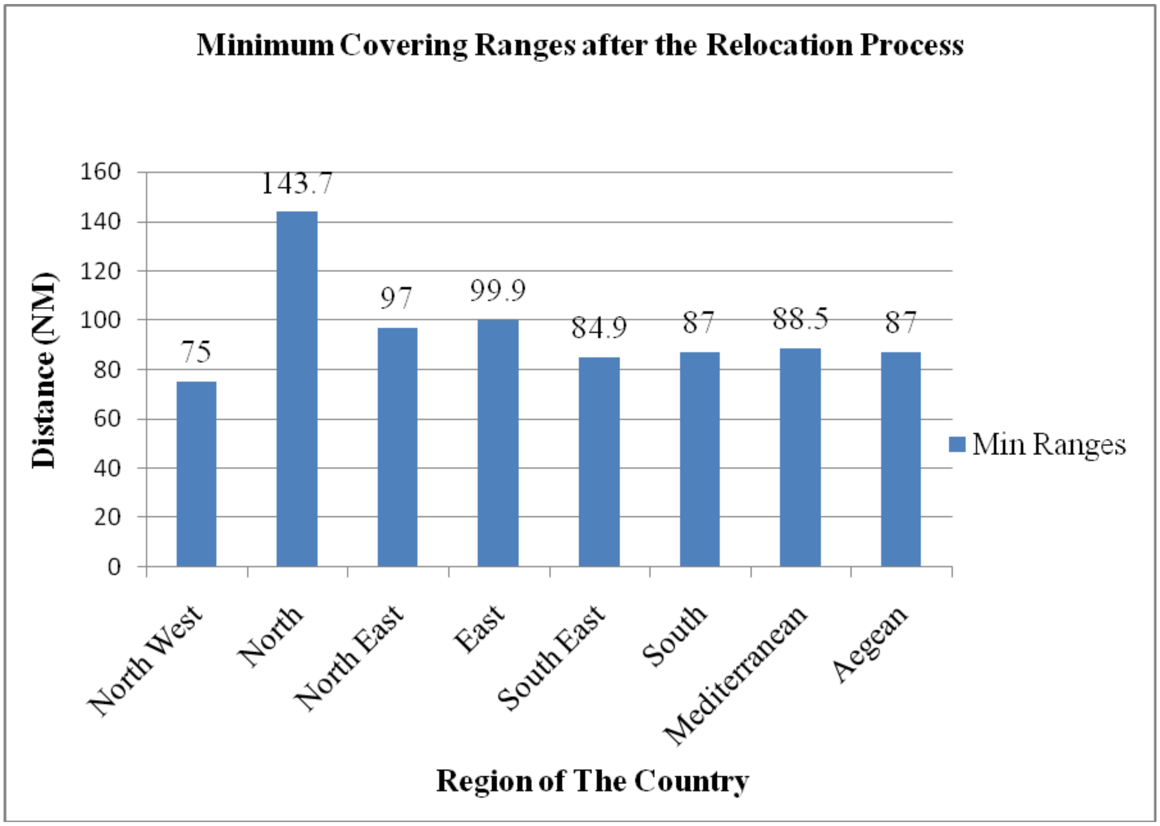


Figure 33. Minimum Covering Ranges after Relocation

In order to see the changes in the solution, one of the demand points which were forced to be covered by the aircraft was assigned as a varible. Figure 34 shows the change in the solution. When the demand point 3741 is set as a variable, aircraft loations are changed to cover the maximal demand points. The aircraft are located to COPs 30, 111, 209, 714, 876, 977, 1149, 1163. 1579 demand points are covered so the coverage rate is 68.74%. Although the coverage rate is higher than the previous solution, desired minimum coverage distances on the north and the north east are not obtained.

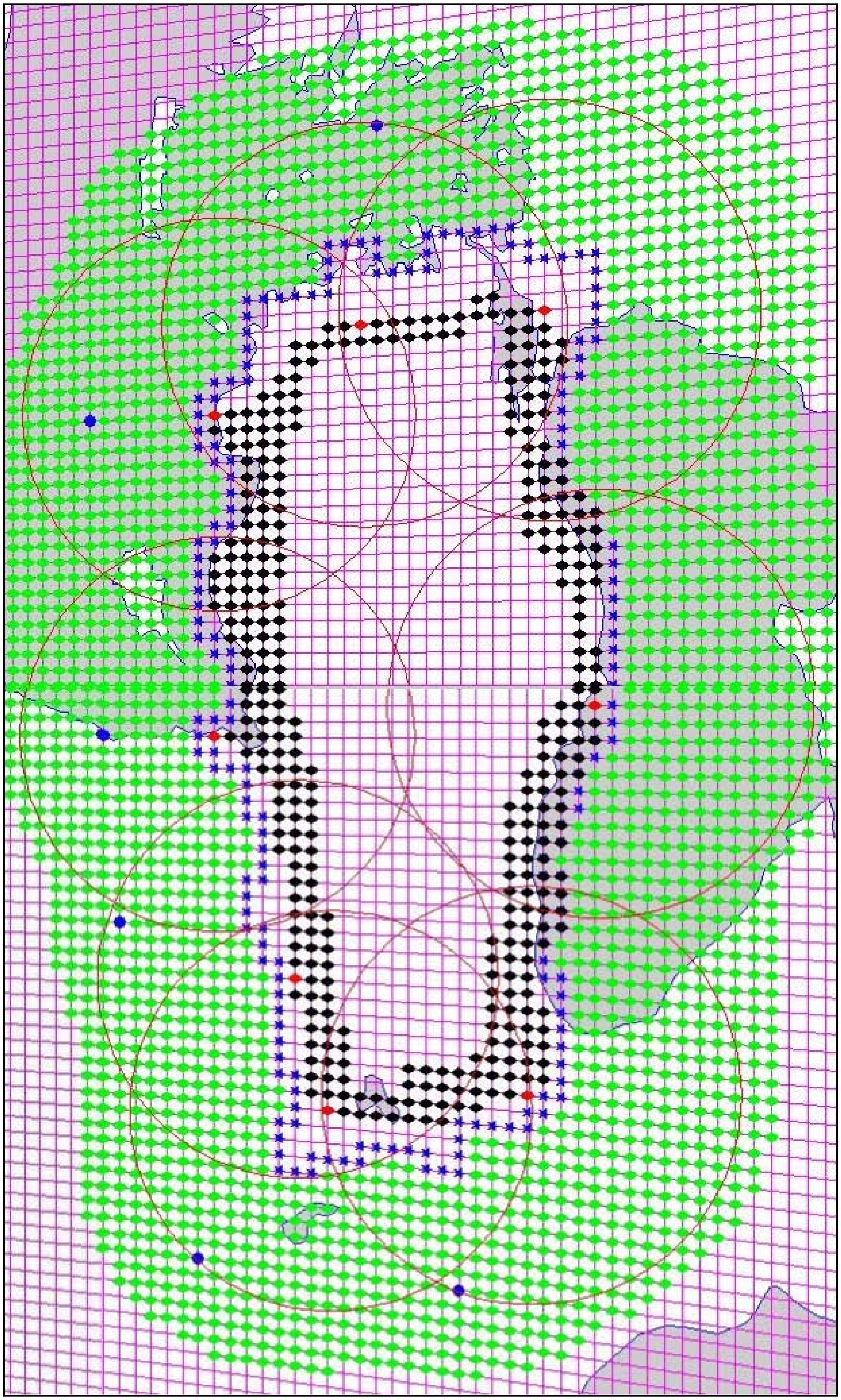


Figure 34. Changes in the Solution (Demand Point 3741 is variable)

The western and the eastern scenarios’ solutions are combined and the result is shown in Figure 35. When the aircraft are located at COPs 19, 93, 209, 324, 876, 938, 1022 and 1155, the coverage rate is 65.39% and 1502 demand points are covered.

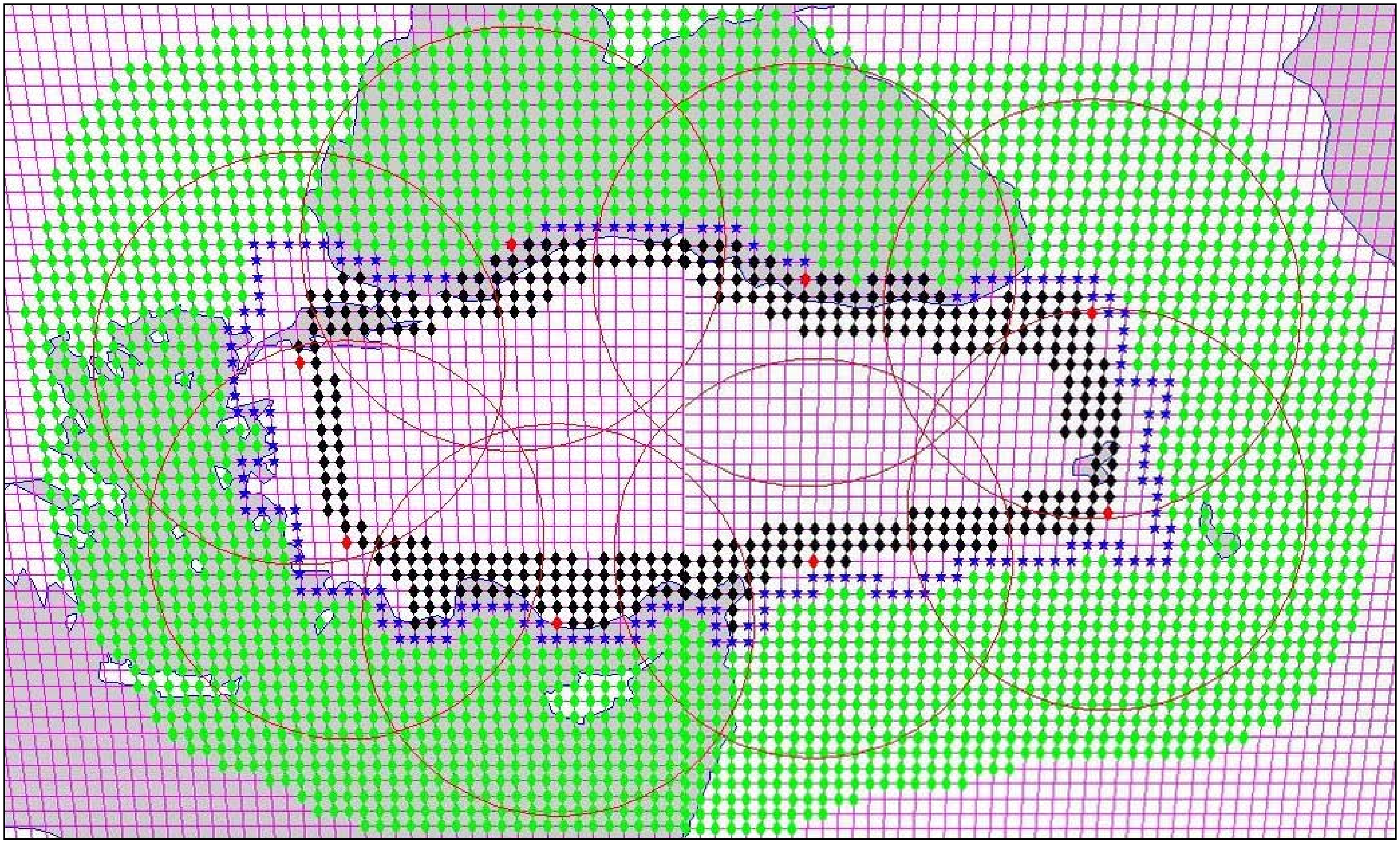


Figure 35. Combination of the Western and the Eastern Scenarios

Table 8. Result Report of Combination of the Scenarios

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	20%	8	65.39%	75
North				104.5
North East				120.4
East				99.9
South East				84.9
South				87
Mediterranean				88.5
Aegean				87

Table 8 shows the coverage rate and the minimum covering ranges according to the respective parts of the country. The same solution could be obtained by forcing the aircraft to cover the demand points 1449, 1564, 2655, 2863, 3506, 3741, 3985, 4073 and 4153. Figure 36 shows the minimum covering ranges as a graphical illustration.

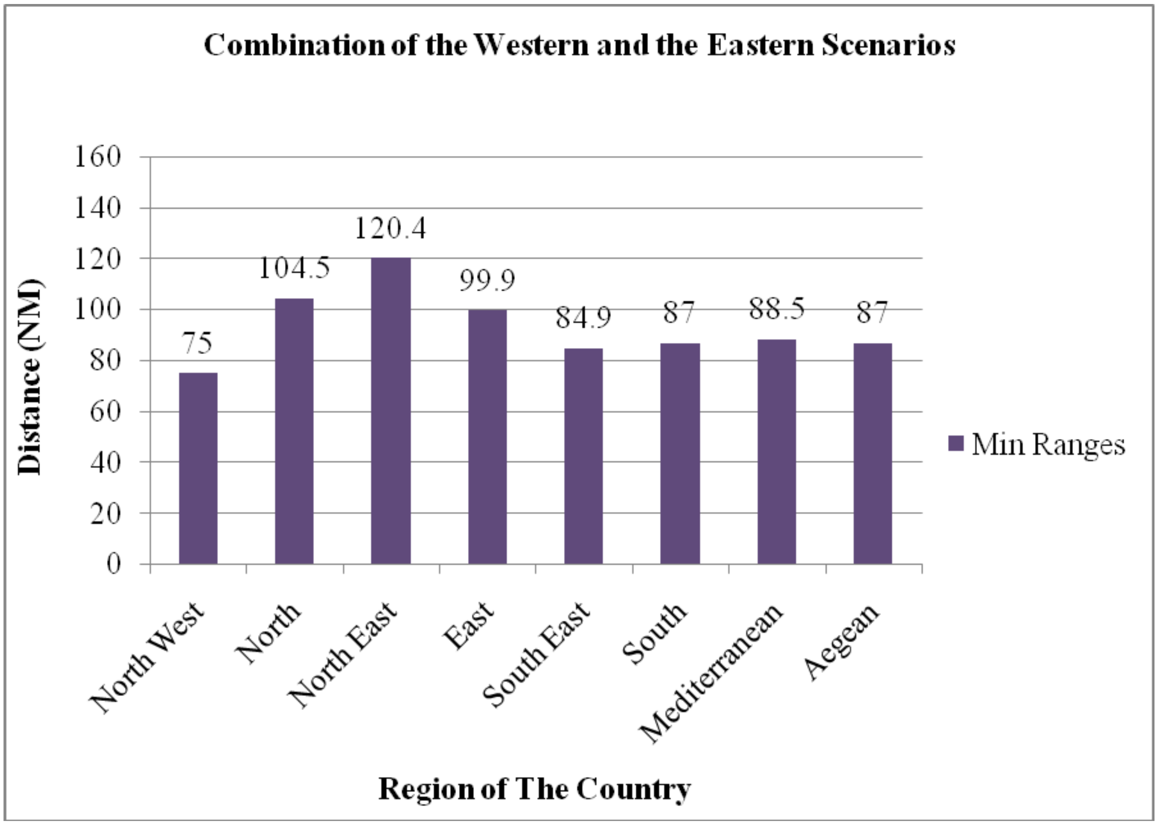


Figure 36. Illustration of the Combination of the Scenarios

The minimum distance in the north west could require attention because it is 75 NM. If the aircraft at the COP 324 is moved to COP 270 to increase this coverage distance, the minimum coverage distance can not be obtained on the Aegean Sea. If the aircraft is moved to COP 270 the minimum coverage distances become 83.4 on the AegeanSea, and 88 NM on the north west part of the country. An illustration of a comparison of the minimum coverage distances according to the initial solution and the solution of the combination of the western and the eastern scenarios is shown in Figure 37.

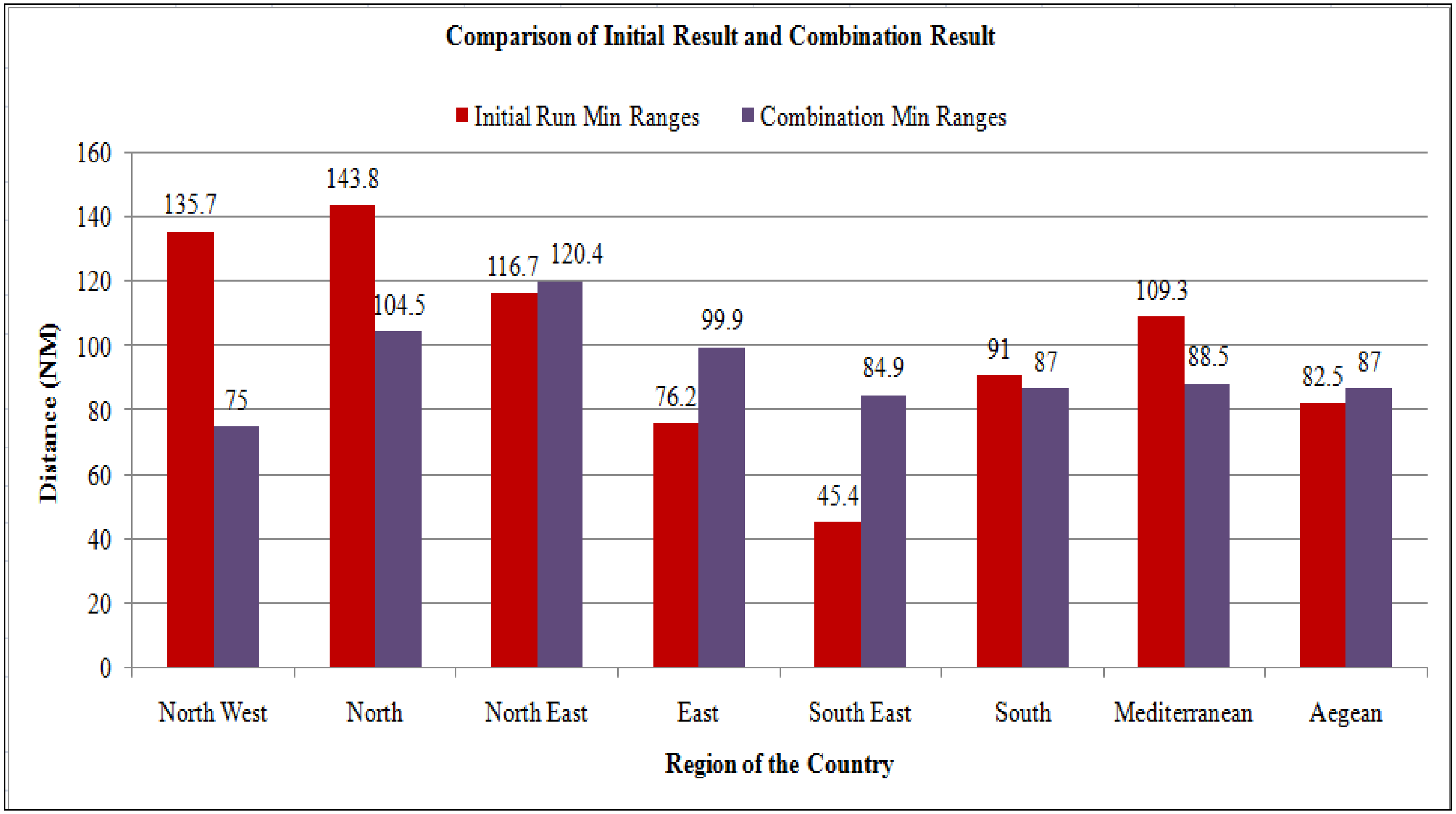


Figure 37. Comparison of Initial Result and Combination Result

Since the number of the COPs on the west is limited, there is not much choice to locate the aircraft in the west. Because of this, when the desired minimum coverage distance is obtained on the Aegean Sea, the minimum coverage distance in the north west part of the country decreases to 75 NM.

4.5 Combination of the Two Scenarios with Seven Aircraft

The optimization program was run for seven aircraft. Then, in order to see if the minimum desired coverage ranges could be obtained by seven aircraft, some demand points were forced to be covered. Initial results for seven aircraft are shown in Figure 38. The aircraft are located at COPs 29, 111, 156, 828, 929, 1149 and 1163. The coverage rate is 67.73% and the number of the covered demand points is 1557. It can easily be seen that the desired minimum coverage distances in the north west, north east, east and the south east parts of the country were not obtained. In order to obtain the desired minimum coverage distances, the same priorities for the regions were used as mentioned earlier.

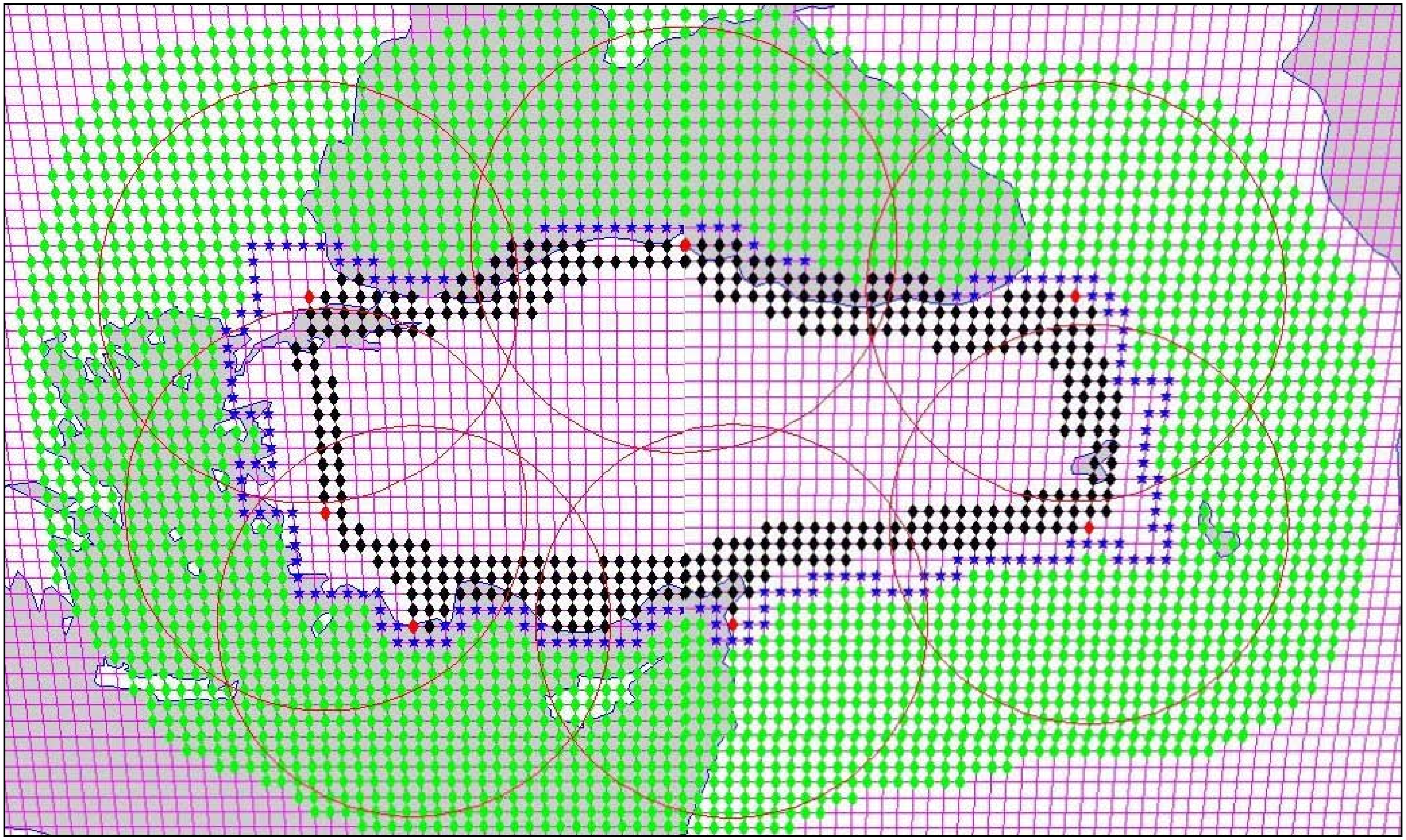


Figure 38. Initial Solution (Seven Aircraft and 20% Risk)

Table 9. Result Report of Initial Run for Seven Aircraft

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	20%	8	65.39%	67.7
North East				39
East				79.2
South East				45.4
South				91
Mediterranean				109.3
Aegean				82.5

Table 9 shows the coverage rate and the minimum coverage distances according to the initial run for seven aircraft. Minimum coverage distances in the north east and in the south east are very low. The desired minimum coverage distances were not obtained for the east part and north west part of the country.

In order to obtain the desired minimum distances, aircraft are forced to cover the demand points 2740, 2863, 3420, 3741, 3987. The solution after the relocation is shown in Figure 39. The aircraft are located to COPs 28, 156, 324, 876, 938, 1024, 1155. The coverage rate is 62.53% and the number of the covered demand points is 1437.

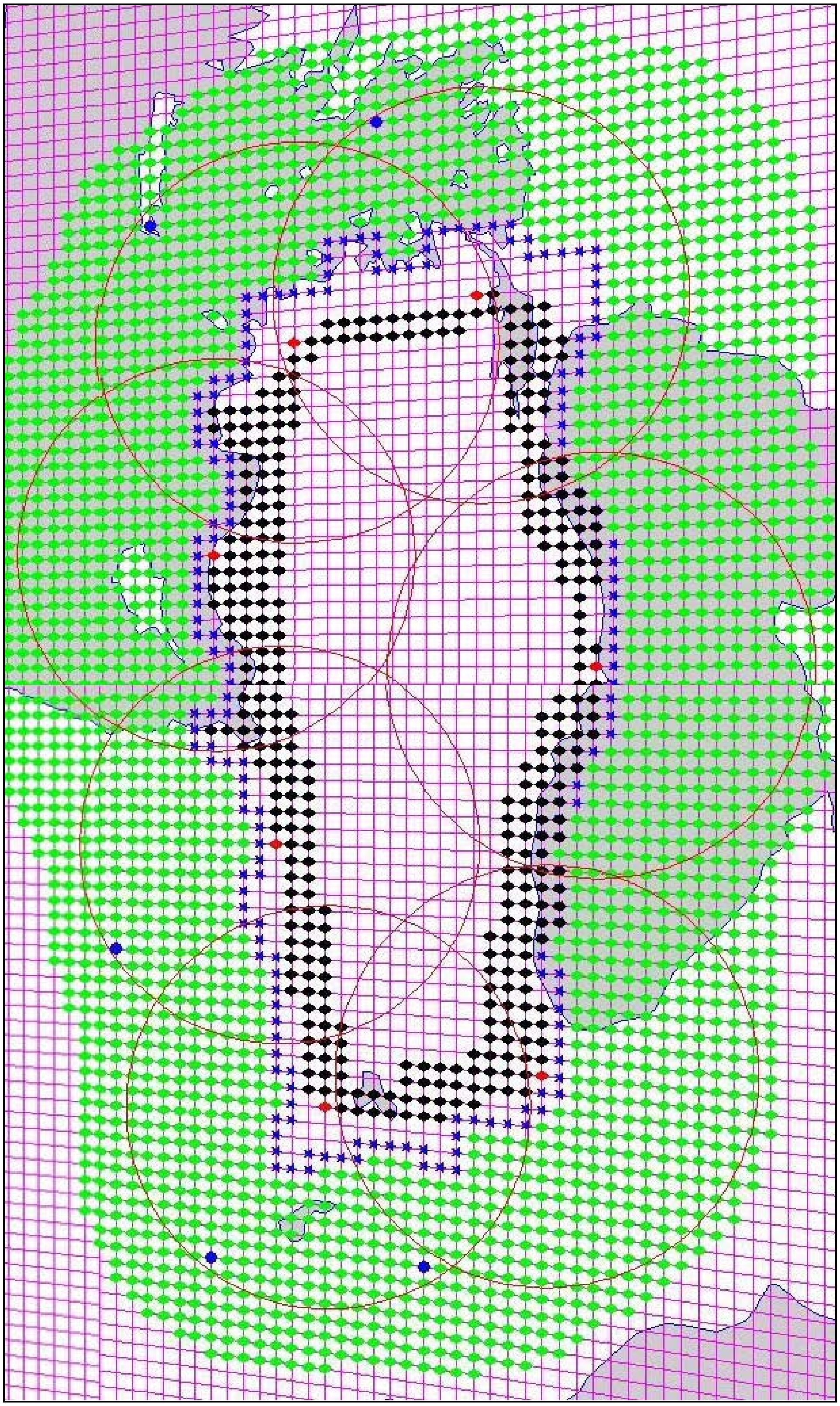


Figure 39. Solution after Relocation (Seven Aircraft and 20% Risk)

Table 10. Result Report of Relocation for Seven Aircraft

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	20%	8	62.53%	48.5
North East				52.6
East				85.7
South East				80.7
South				73
Mediterranean				88.5
Aegean				87

Minimum coverage distances are obtained except for the north west, north east and south east regions of the country. Seven aircraft cannot cover the minimum desired covering ranges for accepted 20% risk. Because of this, risk was increased to 30% to see the change in the minimum covering ranges. The optimization program was run for seven aircraft with accepted 30% risk and then some demand points were forced to be covered by the aircraft to obtain the minimum desired covering ranges. Figure 40 shows the result of the initial run for seven aircraft with 30 % risk.

After the initial run, 1557 demand points are covered so the coverage rate is 67.74%. The aircraft are located at the COPs 29, 111, 156, 828, 929, 1149 and 1155.

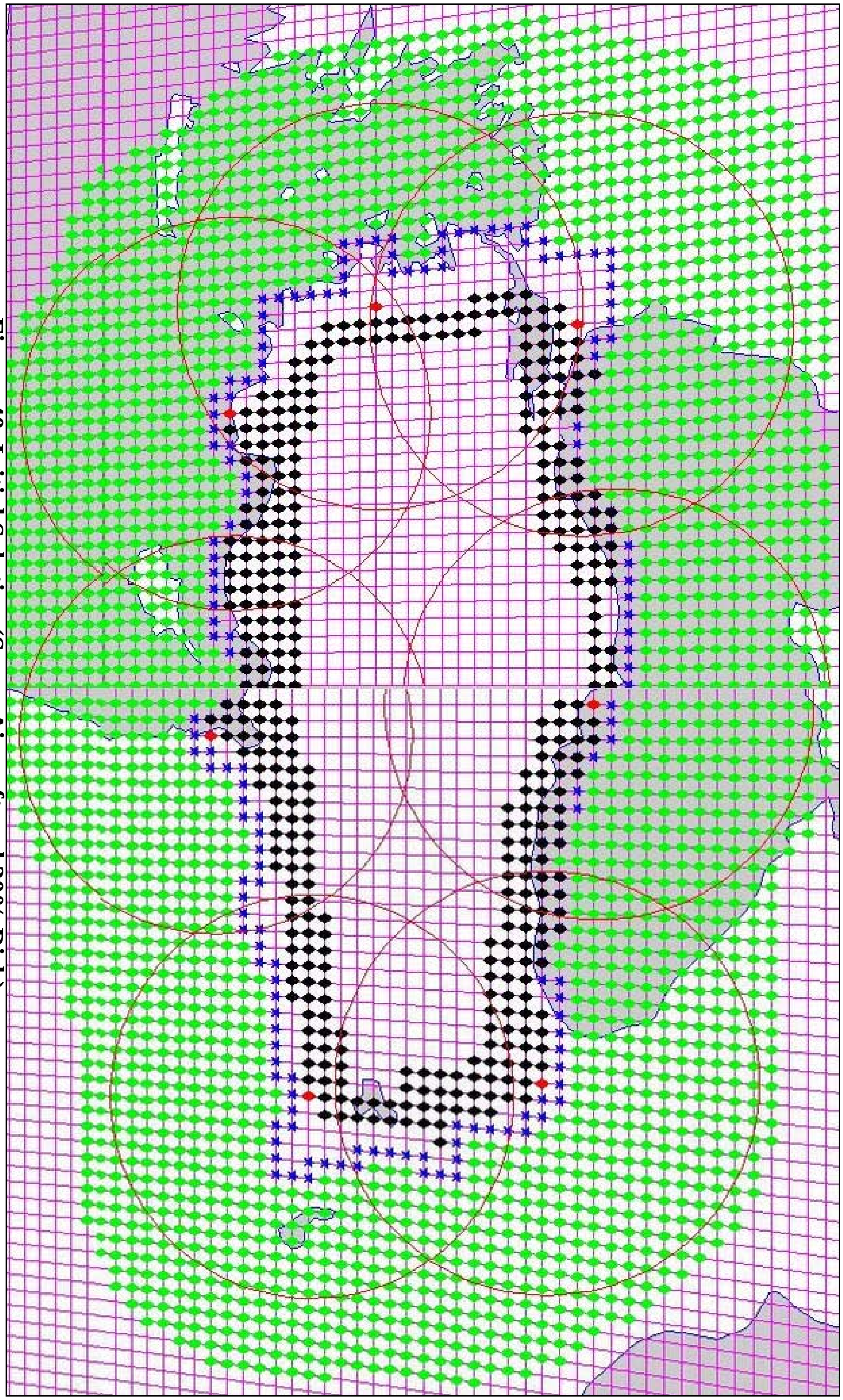


Figure 40. Initial Solution (Seven Aircraft and 30% Risk)

Table 11. Result Report of Initial Run for Seven Aircraft

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	30%	8	67.74%	67.7
North East				76.5
East				76.2
South East				45.4
South				91
Mediterranean				109.3
Aegean				82.5

It can easily be seen from Table 11 that there is not much difference between the initial result for seven aircraft with 20% risk scenario and the initial result for seven aircraft with 30% risk scenario. Since the desired minimum coverage distances in the Aegean Sea, the east, the south east and the north west parts of the country could not be obtained, the aircraft were relocated. The result of the relocation is shown in Figure 41.

Demand points 2740, 2863, 3082, 3420, 3841, 3987, 4072 and 4355 are forced to be covered by the aircraft. The coverage rate is 62.57% and 1438 demand points are covered. Solution time of the optimization is 7.29 seconds. The aircraft are relocated to COPs 28, 156, 324, 876, 938, 1025 and 1155.

Figure 41. Solution after Relocation (Seven Aircraft and 30% Risk)

Table 12. Result Report of Relocation for Seven Aircraft

Region	Risk	AEW&C	Coverage Rate	Min Range from Borders (NM)
North West	30%	8	62.57%	48.5
North East				52.63
East				85.72
South East				75
South				64
Mediterranean				88.5
Aegean				87

There is not much difference between the solution after relocation of 20% risk scenario and the solution after relocation of 30% risk scenario. The north west, the north east, the south east and the south parts of Turkey could not be covered as desired.

4.6 Conclusion

The initial run with eight aircraft provides an optimal solution for this research's MCLP model according to 20% risk condition. Then the minimum covering distances were obtained with eigth aircraft for 185 NM covering radius. Turkey needs eight AEW&C aircraft to cover minimum desired ranges in the worst environmental conditions according to this research.

185NM covering radius is an approximate distance. Seven aircraft may also be enough with a covering radius greater than 185 NM range. This research provides

maximal covering locations of the AEW&C aircraft according to the inputs. Sensitivity analysis was applied to see the changes in the solutions. Accurate input data may change the results.

Although the research's MCLP model finds the optimum locations of the aircrafts for the maximal cover, some coverage gaps exist. In order to balance the gaps, the aircraft were relocated. After the relocation, the gaps are balanced; however, the coverage rate decreased.

V. Conclusion and Recommendations

5.1 Summary

General information about Turkey and background of the problem were presented in Chapter 1. The general air defense system, the Turkish air defense system and the importance of the AEW&C aircraft are briefly reviewed. General information about Turkish AEW&C aircraft and "Project Peace Eagle" was presented. The literature review is presented in Chapter 2. Specifications of Turkish AEW&C aircraft, general information about the adversary SAM systems and scenarios are introduced. Location problem types were reviewed, followed by a discussion of COP generation. Then, MATLAB® Optimization Toolbox™ and Mapping Toolbox™ are presented. The MCLP model is used to solve the problem of this research using the MATLAB® Optimization Toolbox™. The illustrations were shown using MATLAB® Mapping Toolbox™. The research MCLP model, the methodology used in this research, is discussed in Chapter 3. Risk and the computation of the risk are introduced. Chapter 3 also presents the generation of the MCLP formulation in MATLAB® programming language. Generation of the COPs and demand points are also introduced. The results of the scenarios and the analyses of these results were presented in Chapter 4. A western scenario and an eastern scenario were discussed, followed by the analysis of the combination of these two scenarios. Conclusions, recommendations and suggestions for future research are presented in Chapter 5.

5.1 Research Conclusion and Contributions

One of the most common problems in the operational sciences is facility location problem. This research uses the MCLP model to locate the AEW&C aircraft in the Turkish air space. The MCLP is one of the most common facility location models in operations research. The model was coded in MATLAB® programming language and map illustrations were shown using the MATLAB® Mapping Toolbox™. Model parameters can easily be changed and constraints can be improved or changed.

This research effort provides orbit points for Turkish AEW&C on a plane. The objective of this research is to cover the borders of Turkey as far as possible. Although the MCLP model finds the optimal locations for maximal covering, some gaps reveal according to 185 NM range of the AEW&C aircraft. These gaps are balanced by relocating the aircraft using sensitivity analysis and by compromising the coverage distance on the north part of the country, since the safest part of the country is to the north.

The research shows that Turkey needs eight AEW&C aircraft to cover the borders of the country in the worst conditions. Since there exist gaps even locating eight aircraft, less than eight aircraft would not cover all the borders. The data used for SAM missiles and airfield ranges were realized by making some assumptions. These assumptions can easily be changed by the analysts after determining the exact ranges.

The research's model can be used for other applications such as determining the orbit locations of combat air patrol (CAP) aircraft protecting a certain region. The risk values and the method of the risk's computation may easily be changed or removed by

decision makers. The research's method could also be used to locate RADAR sites, communication antennas

5.3 Future Research

The model's constraints could be changed or new constraints could be included. Demand point reduction could be considered or targets could be used as demand points. Scheduling could be programmed for the escort aircraft that protect the AEW&C aircraft. Air refueling was not taken into consideration in this research. Additional constraints which include air refueling support and friendly airbases that could be used in case of an emergency, could be included. The terrain restrictions on how far the AEW&C aircraft can see from a COP could also be included to portray more realistic scenarios.

The research does not provide an algorithm in order to balance the coverage gaps. Research could be done to provide an algorithm to balance the coverage gaps in case of a limited budget constraint.

Appendix A: Explanations of Using 'linprog' and 'bintprog' Commands

Syntax of 'linprog' Command

This section explains only some of the syntax of the 'linprog' command.

x = linprog(f,A,b), solves min f ' x, such that; Ax ≤ bx. f is avector contains the coefficients of the objective function.

x = linprog(f,A,b,Aeq,beq), solves min f' x, such that; Ax ≤ b and Aeq = beq. If there are no inequality constraints, then A and b must be set to empty. (A=[]; b=[];)

x = linprog(f,A,b,Aeq,beq,lb,ub) defines lower bound and upper bound vectors of variable x. If there are no qeuality constraints, Aeq and beq must be set to empty. (Aeq=[]; beq=[];)

x = linprog(problem), gives the x values an a vector x, after solving the problem.

[x,fval] = linprog(...), additionally, gives the objection function value as 'fval', at solution x,

[x,fval,exitflag] = linprog(...), additionally, gives a value 'exitflag' which describes the exit condition.

[x,fval,exitflag,output] = linprog(...), ,additionally, gives a structure output which contains information about the optimization.

[x,fval,exitflag,output,lambda] = linprog(...), additionally, gives the lagrange multipliers in 'lambda'.

An Example of Using 'linprog' Command

Max z $= -x_1 + 3x_2$

Subject to:

$$x_1 + x_2 \geq 1$$

$$-2x_1 + 3x_2 \leq 6$$

$$x_2 \leq 2$$

$$x_1 \ , \ \ x_2 \geq 0$$

To use the command, the mathematical model above must be adapted to a minimization problem and constraints must be converted to less than or equal to constraints. The mathematical model above is equal to the mathematical model shown below.

$$\text{Min } z \quad = \quad x_1 - 3x_2$$

Subject to:

$$-x_1 - x_2 \leq -1$$

$$-2x_1 + 3x_2 \leq 6$$

$$x_2 \leq 2$$

$$0 \leq x_1 \ , \ \ x_2$$

Now the problem is ready to be solved. The commands below shows how to set the values of f, A, and b and solve the problem

```
f = [ 1 -3 ];    A = [ -1 -1 ; -2 3 ; 0 1 ];   b = [ -1 ; 6 ; 2 ];  lb = zeros(2,1);
[ x, fval ] = linprog (f, A, b, [], [], lb);
```

The values of the solution as follows:

x=[0 ; 2] wich menas, x1=0, x2=2, fval = − 6, Wich is the optimal objective function value of the minimization problem. Optimal objective function value of the maximization problem is 6.

An Example of Using 'bintprog' Command

Max z = $9x_1 + 5x_2 + 6x_3 + 4x_4$

Subject to:

$$6x_1 + 3x_2 + 5x_3 + 2x_4 \le 9$$

$$x_3 + x_4 \le 1$$

$$x_1 - x_3 \ge 0$$

$$x_2 - x_4 \ge 0$$

$$x_i \in \{0,1\}$$

To use the command, the mathematical model above must be adapted to a minimization problem and constraints must be converted to less than or equal to constraints. The mathematical model above is equal to the mathematical model shown below.

Min z = $-9x_1 - 5x_2 - 6x_3 - 4x_4$

Subject to:

$$6x_1 + 3x_2 + 5x_3 + 2x_4 \le 9$$

$$x_3 + x_4 \le 1$$

$$-x_1 + x_3 \le 0$$

$$-x_2 + x_4 \le 0$$

$$x_i \in \{0,1\}$$

Now the problem is ready to be solved. The commands below shows how to set the values of f, A, and b and solve the problem.

```
f = [ -9 ; -5 ; -6 ; -4 ];  A = [ 6 3 5 2 ; 0 0 1 1; -1 0 1 0; 0 -1 0 1 ]; b = [9 ; 1 ; 0 ; 0];
[ x , fval ] = bintprog ( f , A , b );
```

The values of the solution as follows:

x = [1 ; 1 ; 0 ; 0] which means, $x_1 = 1$, $x_2 = 1$, $x_3 = 0$, $x_4 = 0$, fval = −14 which is the optimal objective function value of the minimization problem. Optimal objective function value of maximization problem is 14.

Appendix B: Source Code of the Model

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%% CREATE SQUARE GRIDS  %%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [grid_mtrx_lat,grid_mtrx_lon]=crt_grds(turkiye,lat_ind,lon_ind,...
    start_lat,start_lon)
%%%%%%%%%%%%%%% CREATE LATITUDES  %%%%%%%%%%%%%%%%%
grid_mtrx_lat(lat_ind,1)=start_lat;
lon=start_lon;
track_lat_lon=zeros(100,2);
track_lat_lon(100,1)=grid_mtrx_lat(lat_ind,1);
 for i=lat_ind+1:length(turkiye(:,1))+1
      [track_lat_lon]=track1('rh',track_lat_lon(100,1),lon,180,nm2deg(15));
      grid_mtrx_lat(i,1)=track_lat_lon(100,1);
end
 track_lat_lon(100,1)=start_lat;
 for i=lat_ind-1:-1:1
      [track_lat_lon]=track1('rh',track_lat_lon(100,1),lon,360,nm2deg(15));
      grid_mtrx_lat(i,1)=track_lat_lon(100,1);
end
 temp=grid_mtrx_lat;
for i=1:length(turkiye(1,:))
      grid_mtrx_lat=horzcat(grid_mtrx_lat,temp);
end
 %%%%%%%%%%%%%%% CREATE LONGITUDES %%%%%%%%%%%%%%%
 for j=lat_ind:length(turkiye(:,1))+1;
      grid_mtrx_lon(j,lon_ind)=lon;
      track_lat_lon=zeros(100,2);
      track_lat_lon(100,2)=lon;
     for i=lon_ind:length(turkiye(1,:))
```

```
        [track_lat_lon]=track1('rh',grid_mtrx_lat(j,i),...
                                  track_lat_lon(100,2),90,nm2deg(15));
        grid_mtrx_lon(j,i+1)=track_lat_lon(100,2);
    end
end
for j=lat_ind:-1:1;
    grid_mtrx_lon(j,lon_ind)=lon;
    track_lat_lon=zeros(100,2);
    track_lat_lon(100,2)=lon;
   for i=lon_ind:-1:2
       [track_lat_lon]=track1('rh',grid_mtrx_lat(j,i),...
                              track_lat_lon(100,2),270,nm2deg(15));
      grid_mtrx_lon(j,i-1)=track_lat_lon(100,2);
   end
end
for j=lat_ind+1:length(turkiye(:,1))+1;
     grid_mtrx_lon(j,lon_ind)=lon;
     track_lat_lon=zeros(100,2);
     track_lat_lon(100,2)=lon;
    for i=lon_ind:-1:2
        [track_lat_lon]=track1('rh',grid_mtrx_lat(j,i),...
                              track_lat_lon(100,2),270,nm2deg(15));
        grid_mtrx_lon(j,i-1)=track_lat_lon(100,2);
    end
end
for j=lat_ind:-1:1;
   grid_mtrx_lon(j,lon_ind)=lon;
   track_lat_lon=zeros(100,2);
   track_lat_lon(100,2)=lon;
   for i=lon_ind:length(turkiye(1,:))
```

```
   [track_lat_lon]=track1('rh',grid_mtrx_lat(j,i),...
                                                  track_lat_lon(100,2),90,nm2deg(15));
   grid_mtrx_lon(j,i+1)=track_lat_lon(100,2);
  end
end
 %%%%%%%%%% PLOT THE MERIDIANS ON THE MAP %%%%%%%%%%%%
for i=1:length(grid_mtrx_lat(:,1))-1
  for j=1:length(grid_mtrx_lon(1,:))
  trk=track2(grid_mtrx_lat(i,j),grid_mtrx_lon(i,j),...
                    grid_mtrx_lat(i+1,j),grid_mtrx_lon(i+1,j));
  plotm(trk(:,1),trk(:,2),'m')
  end
end
 %%%%%%%%%% PLOT THE PARALLELS ON THE MAP  %%%%%%%%%%%%
 n=length(grid_mtrx_lat(1,:));
 for i=1:length(grid_mtrx_lat(:,1))
   trk=track2('rh',grid_mtrx_lat(i,1),grid_mtrx_lon(i,1),...
                                                  grid_mtrx_lat(i,n),grid_mtrx_lon(i,n));
   plotm(trk(:,1),trk(:,2),'m-')
 end
 end
%%%%%%%%%%% END OF CREATE SQUARE GRIDS %%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%% COP NUMERATION %%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [turkiye_points,A_num_c]=cnd_pt_num(turkiye,grid_mtrx_lat,...
                                                              grid_mtrx_lon)
%%%%%%% FIND THE POINTS WITHIN TURKEY BORDERS  %%%%%%%%%%%
%%%%%%%%%%%% AND NUMERATE THE COPS %%%%%%%%%%%%%%%%%
```

```
k=1;
last=0;
for i=2:length(grid_mtrx_lat(:,1))-1
    for j=2:length(grid_mtrx_lon(1,:))-1
        if ((turkiye(i,j)~=0) && (turkiye(i-1,j)==0)) || ...
                         ((turkiye(i,j)~=0) && (turkiye(i-1,j)~=0))
            one_zero_c(i,j)=1;
            k=k+1;
            if turkiye(i,j+1)==0
                last=1;
            end
        end
        if last==1
            one_zero_c(i,j+1)=1;
            k=k+1;
            last=0;
        end
    end
end
for i=2:length(grid_mtrx_lat(:,1))-1
    for j=2:length(grid_mtrx_lon(1,:))-1
        if (turkiye(i,j)==0) && (turkiye(i-1,j)~=0)
            one_zero_c(i,j)=1;
            k=k+1;
            if turkiye(i-1,j+1)==0
                one_zero_c(i,j+1)=1;
                k=k+1;
            end
        end
    end
```

```
end
k=1;
for i=1:length(one_zero_c(:,1))
    for j=1:length(one_zero_c(1,:))
        if one_zero_c(i,j)==1
            turkiye_points(k,1)=grid_mtrx_lat(i,j);
            turkiye_points(k,2)=grid_mtrx_lon(i,j);
            turkiye_points(k,3)=k;
            A_num_c(i,j)=k;
            k=k+1;
        end
    end
end
m=length(A_num_c(1,:))+1;
A_num_c(1,m:length(grid_mtrx_lon(1,:)))=0;
n=length(A_num_c(:,1))+1;
for i=n:length(grid_mtrx_lat(:,1))
    A_num_c=vertcat(A_num_c,zeros(1,length(grid_mtrx_lon(1,:))));
end
end
%%%%%%%%%%%%%%% END OF COP NUMERATION %%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%% DEMAND POINT NUMERATION %%%%%%%%%%%%%%
%%%%%%%%%%%%%% (AFTER COP NUMERATION) %%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [turkiye_points,A_num_c,A_num_d,dmd_pts_all]=...
                              dmd_pt_num(turkiye,grid_mtrx_lat,grid_mtrx_lon,A_num_c)
if isempty(A_num_c)
   [turkiye_points,A_num_c] = cnd_pt_num(turkiye,grid_mtrx_lat,grid_mtrx_lon);
```

```
end
k=1;
for i=1:length(A_num_c(:,1))
    for j=1:length(A_num_c(1,:))
        if A_num_c(i,j)==0
            A_num_d(i,j)=k;
            dmd_pts_all(k,1)=grid_mtrx_lat(i,j);
            dmd_pts_all(k,2)=grid_mtrx_lon(i,j);
            dmd_pts_all(k,3)=k;
            k=k+1;
        end
        if A_num_c(i,j)~=0
            A_num_d(i,j)=0;
        end
    end
end
%%%%%%%%% END OF DEMAND POINT NUMERATION %%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%% EXCLUDE THE DEMAND POINTS CANNOT BE COVERED %%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [dmd_pts]=exclude_dmd_cannot_covered(dmd_pts,border)
for i=1:length(dmd_pts)
    cover=0;
    if dmd_pts(i,3)~=0
       for k=1:length(border)
           if cover==1
              break;
           end
           if deg2nm(distance('gc',[dmd_pts(i,1),dmd_pts(i,2)],...
```

```
                    [border(k,1),border(k,2)]))<=(200-15)
          cover=1;
          dmd_pts(i,4)=1;
        end
      end
    end
end

index=find(~dmd_pts(:,4));
for k=1:length(index)
    dmd_pts(index(k),3)=0;
end
dmd_pts(:,4)=[];
end
%% % END OF EXCLUDE THE DEMAND POINTS CANNOT BE COVERED %%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%% FIND THE BORDER POINTS OF THE COUNTRY %%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [border]=find_borders(temp_A_num_c,A_num_c,grid_mtrx_lat,...
                                                        grid_mtrx_lon)
k=1;
for i=2:length(temp_A_num_c(:,1))-1
    for j=2:length(temp_A_num_c(1,:))-1
        if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i-1,j)==0)
            border(k,1)=grid_mtrx_lat(i,j);
            border(k,2)=grid_mtrx_lon(i,j);
            border(k,3)=A_num_c(i,j);
            k=k+1;
        end
```

```
if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i+1,j)==0)
    border(k,1)=grid_mtrx_lat(i,j);
    border(k,2)=grid_mtrx_lon(i,j);
    border(k,3)=A_num_c(i,j);
    k=k+1;
end
if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i,j-1)==0)
    border(k,1)=grid_mtrx_lat(i,j);
    border(k,2)=grid_mtrx_lon(i,j);
    border(k,3)=A_num_c(i,j);
    k=k+1;
end
if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i,j+1)==0)
    border(k,1)=grid_mtrx_lat(i,j);
    border(k,2)=grid_mtrx_lon(i,j);
    border(k,3)=A_num_c(i,j);
    k=k+1;
end
if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i-1,j-1)==0)
    border(k,1)=grid_mtrx_lat(i,j);
    border(k,2)=grid_mtrx_lon(i,j);
    border(k,3)=A_num_c(i,j);
    k=k+1;
end
if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i+1,j+1)==0)
    border(k,1)=grid_mtrx_lat(i,j);
    border(k,2)=grid_mtrx_lon(i,j);
    border(k,3)=A_num_c(i,j);
    k=k+1;
end
```

```
        if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i-1,j+1)==0)
            border(k,1)=grid_mtrx_lat(i,j);
            border(k,2)=grid_mtrx_lon(i,j);
            border(k,3)=A_num_c(i,j);
            k=k+1;
        end
        if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i+1,j-1)==0)
            border(k,1)=grid_mtrx_lat(i,j);
            border(k,2)=grid_mtrx_lon(i,j);
            border(k,3)=A_num_c(i,j);
            k=k+1;
        end
    end
end

temp=border;
border=[];
n=length(temp);
for i=1:n
    [a,b]=ismember(temp,temp(i,:));
    for j=i+1:n
        if a(j,:)==[1 1 1]
            temp(j,:)=[0 0 0];
            n=length(temp);
        end
    end
end
border=temp(1,:);
for i=2:length(a)
    if a(i,:)~=[1 1 1];
```

```
        border=vertcat(border,temp(i,:));
    end
end
end
%%%%% END OF FIND THE BORDER POINTS OF THE COUNTRY %%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%% COP RISK ASSIGMENT NEAR THE BORDERS %%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [cop,temp_A_num_c]=border_risk(turkiye_points,A_num_c,border)
border_score1=7;
border_score2=8;
cop=turkiye_points;
temp_A_num_c=A_num_c;
ic=border;
for i=1:length(A_num_c(:,1))
    for j=1:length(A_num_c(1,:))
        if A_num_c(i,j)~=0
           temp_A_num_c(i,j)=10;
        end
    end
end
for m=1:3
    ic(:,4)=border_score1;
    for i=1:length(ic)
        if (ic(i,1)<42.17) && (ic(i,1)>40.42)
           if (ic(i,2)>29.9) && (ic(i,2)<40)
              ic(i,4)=border_score2;
           end
        end
```

```
    end
    for i=1:length(ic)
        cop(ic(i,3),4)=ic(i,4);
    end
k=1;
for i=1:length(A_num_c(:,1))
    for j=1:length(A_num_c(1,:))
        if k<=length(ic)
            if A_num_c(i,j)==ic(k,3)
                temp_A_num_c(i,j)=ic(k,4);
                k=k+1;
            end
        end
    end
end
for i=1:length(A_num_c(:,1))
    for j=1:length(A_num_c(1,:))
        if (temp_A_num_c(i,j)~=0) && (temp_A_num_c(i,j)~=10)
            temp_A_num_c(i,j)=0;
        end
    end
end
[ic]=edge_mtrx(temp_A_num_c,A_num_c,grid_mtrx_lat,grid_mtrx_lon);
border_score1=border_score1+1;
border_score2=border_score2+1;
end
cop(:,4)=cop(:,4)*1/10;
for i=1:length(cop)
    if cop(i,4)==0
        cop(i,4)=1;
```

```
    end
end
end
%%%%%% END OF COP RISK ASSIGMENT NEAR THE BORDERS %%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%% % RISK CALCULATION OF COPs WITHIN RANGE OF THREAT %%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [cop]=Risk_Calculation_within_Range_of_Threat(crt_dst,nm,cop,threat)
for i=1:length(cop)
    for j=1:length(threat)
        dst=deg2nm(distance(threat(j,1),threat(j,2),cop(i,1),cop(i,2)));
        if dst<=crt_dst
            cop(i,4)=0;
        elseif (dst>crt_dst)&& (dst<=crt_dst+nm)
                cop(i,4)=cop(i,4)*1/10;
        elseif (dst>crt_dst+nm)&& (dst<=crt_dst+nm*2)
                cop(i,4)=cop(i,4)*2/10;
        elseif (dst>crt_dst+nm*2)&& (dst<=crt_dst+nm*3)
                cop(i,4)=cop(i,4)*3/10;
         elseif (dst>crt_dst+nm*3)&& (dst<=crt_dst+nm*4)
                cop(i,4)=cop(i,4)*4/10;
         elseif (dst>crt_dst+nm*4)&& (dst<=crt_dst+nm*5)
                  cop(i,4)=cop(i,4)*5/10;
          elseif (dst>crt_dst+nm*5)&& (dst<=crt_dst+nm*6)
                    cop(i,4)=cop(i,4)*6/10;
           elseif (dst>crt_dst+nm*6)&& (dst<=crt_dst+nm*7)
                   cop(i,4)=cop(i,4)*7/10;
           elseif (dst>crt_dst+nm*7)&& (dst<=crt_dst+nm*8)
                     cop(i,4)=cop(i,4)*8/10;
```

```
          elseif (dst>crt_dst+nm*8)&& (dst<=crt_dst+nm*9)
                cop(i,4)=cop(i,4)*9/10;
        end
    end
end
 end
 % % END OF RISK CALCULATION OF COPs WITHIN RANGE OF THREAT %

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%% ELIMINATE LAND BORDERS %%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [cop]=exclude_land_borders(border,cop)
%%%%%%%%%% ELIMINATE EAST LAND BORDER %%%%%%%%%%%%%%
for i=1:length(border)
    if (border(i,1)<41.5) && (border(i,1)>37)
      if (border(i,2)>41) && (border(i,2)<49)
        cop(border(i,3),4)=0;
      end
    end
end
for i=1:length(border)
    if (border(i,1)<38) && (border(i,1)>35)
      if (border(i,2)>35.8) && (border(i,2)<49)
        cop(border(i,3),4)=0;
      end
    end
end
%%%%%%%%%% ELIMINATE WEST LAND BORDER %%%%%%%%%%%%%%
for i=1:length(border)
    if (border(i,1)<42) && (border(i,1)>40.6)
```

```
      if (border(i,2)>25.8) && (border(i,2)<28)
        cop(border(i,3),4)=0;
      end
    end
end
end
%%%%%%%%%% END OF ELIMINATE LAND BORDERS %%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%% ELIMINATE INNER COPS WITHOUT RISK %%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [cop]=eliminate_inner_cops(cop,A_num_c,grid_mtrx_lat,grid_mtrx_lon)
temp=A_num_c;
k=1;
for i=1:length(temp(:,1))
    for j=1:length(temp(1,:))
        if temp(i,j)==k
            if cop(k,4)~=1
                temp(i,j)=0;
            else temp(i,j)=cop(k,4);
            end
            k=k+1;
        end
    end
end
[ic]=edge_mtrx(temp,A_num_c,grid_mtrx_lat,grid_mtrx_lon);
k=1;
for i=1:length(A_num_c(:,1))
    for j=1:length(A_num_c(1,:))
        if k<=length(ic)
```

```
            if A_num_c(i,j)==ic(k,3)
               temp(i,j)=0;
               k=k+1;
            end
         end
     end
end
 index=find(temp);
for i=1:length(index)
    cop(A_num_c(index(i)),4)=0;
end
end
%%%%%%% END OF ELIMINATE INNER COPS WITHOUT RISK %%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%% CREATE MCLP FORMULATION OF THE MODEL %%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [f,A,b]=crt_MCLP_formulation(dmd_pts,turkiye_points,...
                                                            number_of_AEW)
%%%%%%%%%% CREATE OBJECTIVE FUNCTION %%%%%%%%%%%%%%%
n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
    if dmd_pts(i,3)~=0
       f(1,i+length(turkiye_points))=dmd_pts(i,4);
    end
end
%%%%%%%%%%%%%%% CREATE A MATRIX %%%%%%%%%%%%%%%%%
A_demand=sparse(length(dmd_pts),length(dmd_pts));
for i=1:length(dmd_pts)
```

```
    if dmd_pts(i,3)~=0
        A_demand(i,i)=1;
    end
end
 A_cop=sparse(length(dmd_pts),length(turkiye_points));
non_zero_dmd=find(dmd_pts(:,3));
 for i=1:length(non_zero_dmd)
    temp=sparse(1,length(turkiye_points));
    for j=1:length(turkiye_points)
        if deg2nm(distance(dmd_pts(non_zero_dmd(i),1),...
                                        dmd_pts(non_zero_dmd(i),2),...
           turkiye_points(j,1),turkiye_points(j,2)))<=185
           temp(1,j)=-1;
        end
    end
    A_cop(non_zero_dmd(i),:)=temp;
end
 A=horzcat(A_cop,A_demand);
 Aeq=sparse(1,n);
Aeq(1,1:length(turkiye_points))=1;
A=vertcat(A,Aeq);
%%%%%%%% %%%%%%CREATE b VECTOR %%%%%%%%%%%%%%%%%%
b=sparse(length(dmd_pts),1);
no=number_of_AEW;
vertcat(b,no);
%%%%%  END OF CREATE MCLP FORMULATION OF THE MODEL %%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%% MATRICES CHANGES %%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
function [f_new,A_new,b_new,index,index_dmd_pts,index_cop]=...
                                        mtrx_changes(cop,dmd_pts,f,A,no_AEW)
%%%%%%%%%%%%%%% A MATRIX CHANCE  %%%%%%%%%%%%%%%%%%%
index_cop=find(cop(:,4));
t=length(index_cop);
 for i=1:t
    A_chng(:,i)=A(:,index_cop(i));
end
 index_dmd_pts=find(dmd_pts(:,3));
m=length(index_dmd_pts);
n=length(A_chng(1,:));
 k=1;
for i=n+1:n+m
    A_chng(:,i)=A(:,length(cop)+index_dmd_pts(k));
    k=k+1;
end
for i=1:m
    temp_index(i)=index_dmd_pts(i)+length(cop);
end
 index=horzcat(index_cop',temp_index);
 temp_dmd_index=index_dmd_pts;
temp_dmd_index(m+1,1)=length(A(:,1));
l=m+1;
for i=1:l
    A_new(i,:)=A_chng(temp_dmd_index(i),:);
end
%%%%%%%%%% OBJECTIVE FUNCTION VECTOR CHANGE %%%%%%%%%%%
for i=1:length(index)
    f_new(1,i)=f(index(i));
end
```

```
%%%%%%%%%%%%%%%% b VECTOR CHANGE %%%%%%%%%%%%%%%%%%
b_new=sparse(m,1);
b_new(length(b_new)+1,1)=no_AEW;
end
%%%%%%%%%%%%%% END OF MATRICES CHANGES %%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%% SHOW THE POINTS AND CIRCLES ON THE MAP %%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function show_on_the_map(coordinates,type,point,circle,radius)
if length(type)==3 & type=='SAM'
   mec='r'; mfc='r'; mrkr='o';
elseif length(type)==6 & type=='border'
   mec='b'; mfc='b'; mrkr='pentagram';
elseif length(type)==3 & type=='cop'
   mec='k'; mfc='k'; mrkr='d';
elseif length(type)==7 & type=='dmd_pts'
   mec='r'; mfc='r'; mrkr='o';
elseif length(type)==8 & type=='fig_base'
   mec='g'; mfc='y'; mrkr='o';
elseif length(type)==3 & type=='sol'
   mec='r'; mfc='r'; mrkr='d';
end
 %%%%%%%%%%%%%%%%%%%%%% SHOW POINTS %%%%%%%%%%%%%%%%
if nargin==3
  for i=1:length(coordinates)
      if coordinates(i,4)~=0
         geoshow(coordinates(i,1),coordinates(i,2),'DisplayType',...
        'point','markeredgecolor',mec,'markerfacecolor',mfc,'marker',mrkr)
      end
```

```
  end
end
%%%%%%%%% SHOW POINTS AND RANGE CIRCLES  %%%%%%%%%%%%
if nargin==5
for i=1:length(coordinates)
   radii(i,1)=nm2deg(radius);
end
 for k=1:length(coordinates)
   [z1,z2] = scircle1(coordinates(k,1),coordinates(k,2),radii(k,1));
   geoshow(coordinates(:,1),coordinates(:,2),'DisplayType','point',...
  'markeredgecolor',mec,'markerfacecolor',mfc,'marker',mrkr)
   geoshow(z1,z2,'DisplayType','line','color',mec,'linestyle','-')
end
end

end
%%%%% END OF SHOW THE POINTS AND CIRCLES ON THE MAP %%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%% SOLVE THE MCLP %%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [real_sol]=solve_MCLP(f,A,b,index,no_AEW,cop)
x=bintprog(f,A,b);
solution=find(x);
for i=1:no_AEW
real_sol(i)=index(solution(i));
end
show_on_the_map(cop,'cop',1)
for i=1:no_AEW
    sol(i,1)=cop(real_sol(i),1);
```

```
    sol(i,2)=cop(real_sol(i),2);
end
show_on_the_map(sol,'sol',1,1,185)
end
%%%%%%%%%%%% END OF SOLVE THE MCLP %%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%% WESTERN SCENARIO %%%%%%%%%%%%%%% %
% % % % %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [west_dmd_pts,west_cop,f_new,A_new,b_new,index,index_dmd_pts,...
                    index_cop]=western_sc(risk,dmd_pts,cop,A,f,no_AEW)
%%%%% ELIMINATE THE COPS AND DEMAND POINTS %%%%%%%%%%%%
%%%%%%%%%%%  EAST OF 35 DEGREE LONGITUDE %%%%%%%%%%%%%
west_dmd_pts=dmd_pts;
west_cop=cop;
 for i=1:length(dmd_pts)
   if dmd_pts(i,2)>35.003356
       west_dmd_pts(i,3)=0;
       west_dmd_pts(i,4)=0;
   end
end
for i=1:length(cop)
   if cop(i,2)>35.003356
        west_cop(i,4)=0;
   end
end
for i=1:length(west_cop)
   if west_cop(i,4)<(1-risk)
      west_cop(i,4)=0;
   end
```

```
end
[f_new,A_new,b_new,index,index_dmd_pts,index_cop]=...
                    mtrx_changes(west_cop,west_dmd_pts,f,A,no_AEW);
end
%%%%%%%%%%% END OF WESTERN SCENARIO %%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%% RUN WESTERN SCENARIO %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [real_sol,percent,covered_dmd_pts]=run_western_sc...
                                        (cop,turkiye_points,dmd_pts,risk,A,no_AEW)
open('only_grids_west_dmd_pts.fig')
for i=1:length(dmd_pts)
   if dmd_pts(i,3)~=0
     dmd_pts(i,4)=-100;
   end
end
n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
   if dmd_pts(i,3)~=0
     f(1,i+length(turkiye_points))=dmd_pts(i,4);
   end
end
[west_dmd_pts,west_cop,f_new,A_new,b_new,index,index_dmd_pts,...
                              index_cop]=western_sc(risk,dmd_pts,cop,A,f,no_AEW);
for i=1:length(west_cop)
   if west_cop(i,4)~=0
     geoshow(west_cop(i,1),west_cop(i,2),'DisplayType',...
     'point','markeredgecolor','k','markerfacecolor','k','marker','d')
```

```
    end
end
[real_sol]=solve_MCLP(f_new,A_new,b_new,index,no_AEW,west_cop);
x=bintprog(f_new,A_new,b_new);
o=length(find(x));
covered_dmd_pts=o-no_AEW;
percent=(o-4)/1159*100;
end
%%%%%%%%% END OF RUN WESTERN SCENARIO %%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%% WEST RELOCATE %%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [time,Covered_Demand_Points,Coverage_Rate,COPs]=...
  east_relocate(risk,turkiye_points,cop,dmd_pts,cover_pts,index_dmd_pts,...
  index_cop,f,A,no_AEW)
Aeq=sparse(length(cover_pts),length(index_cop));
temp_Aeq=sparse(length(cover_pts),length(index_dmd_pts));

k=1;
for i=1:length(cover_pts)
    for j=1:length(index_dmd_pts)
        if index_dmd_pts(j)==cover_pts(i)
          in_dmd(k)=j;
          k=k+1;
        end
    end
end

j=1;
```

```
for i=1:length(cover_pts)
   temp_Aeq(i,in_dmd(j))=1;
   j=j+1;
end

Aeq=horzcat(Aeq,temp_Aeq);
beq=ones(length(cover_pts),1);
beq=sparse(beq);

open('only_grids_west_dmd_pts.fig')

for i=1:length(cover_pts)
   geoshow(dmd_pts(cover_pts(i),1),dmd_pts(cover_pts(i),2),...
   'DisplayType','point','markeredgecolor','b','markerfacecolor',...
   'b','marker','o')
end

n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
   if dmd_pts(i,3)~=0
      f(1,i+length(turkiye_points))=dmd_pts(i,4);
   end
end
[east_dmd_pts,east_cop,f_new,A_new,b_new,index,index_dmd_pts,...
                  index_cop]=western_sc(risk,dmd_pts,cop,A,f,4);
for i=1:length(west_cop)
   if east_cop(i,4)~=0
      geoshow(west_cop(i,1),west_cop(i,2),'DisplayType',...
      'point','markeredgecolor','k','markerfacecolor','k','marker','d')
```

```
    end
end

time1=cputime;
x=bintprog(f_new,A_new,b_new,Aeq,beq);
time2=cputime;
time=time2-time1;
solution=find(x);
for i=1:no_AEW
real_sol(i)=index(solution(i));
end

for i=1:no_AEW
     sol(i,1)=cop(real_sol(i),1);
     sol(i,2)=cop(real_sol(i),2);
end
show_on_the_map(sol,'sol',1,1,185)
COPs=real_sol;
Covered_Demand_Points=solution-no_AEW;
Coverage_Rate=(solution-4)/1159*100;
end
%%%%%%%%%%%%% END OF WEST RELOCATION %%%%%%%%%%%%%



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%% EASTERN SCENARIO %%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [east_dmd_pts,east_cop,f_new,A_new,b_new,index,index_dmd_pts,...
                    index_cop]=eastern_sc(risk,dmd_pts,cop,A,f,no_AEW)
%%%%%%% ELIMINATE THE COPS AND DEMAND POINTS %%%%%%%%%%
```

```
%%%%%%%%%%% EAST OF 35 DEGREE LONGITUDE %%%%%%%%%%%%%
east_dmd_pts=dmd_pts;
east_cop=cop;
for i=1:length(dmd_pts)
    if dmd_pts(i,2)<35.003356
        east_dmd_pts(i,3)=0;
        east_dmd_pts(i,4)=0;
    end
end
for i=1:length(cop)
    if cop(i,2)<35.003356
         east_cop(i,4)=0;
    end
end
for i=1:length(east_cop)
    if east_cop(i,4)<(1-risk)
       east_cop(i,4)=0;
    end
end
[f_new,A_new,b_new,index,index_dmd_pts,index_cop]=...
                        mtrx_changes(east_cop,east_dmd_pts,f,A,no_AEW);
end
%%%%%%%%%%% END OF EASTERN SCENARIO %%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%% RUN EASTERN SCENARIO %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [real_sol,percent,covered_dmd_pts]=run_eastern_sc...
                                            (cop,turkiye_points,dmd_pts,risk,A,no_AEW)
open('only_grids_east_dmd_pts.fig')
```

```
for i=1:length(dmd_pts)
    if dmd_pts(i,3)~=0
       dmd_pts(i,4)=-100;
    end
end
n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
    if dmd_pts(i,3)~=0
       f(1,i+length(turkiye_points))=dmd_pts(i,4);
    end
end
[eastern_dmd_pts,eastern_cop,f_new,A_new,b_new,index,index_dmd_pts,...
                                    index_cop]=eastern_sc(risk,dmd_pts,cop,A,f,no_AEW);
for i=1:length(east_cop)
    if east_cop(i,4)~=0
       geoshow(east_cop(i,1),east_cop(i,2),'DisplayType',...
       'point','markeredgecolor','k','markerfacecolor','k','marker','d')
    end
end
[real_sol]=solve_MCLP(f_new,A_new,b_new,index,no_AEW,east_cop);
x=bintprog(f_new,A_new,b_new);
o=length(find(x));
covered_dmd_pts=o-no_AEW;
percent=(o-4)/1170*100;
end
%%%%%%%%%% END OF RUN EASTERN SCENARIO %%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%% EAST RELOCATE %%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [time,Covered_Demand_Points,Coverage_Rate,COPs]=...
  east_relocate(risk,turkiye_points,cop,dmd_pts,cover_pts,index_dmd_pts,...
  index_cop,f,A,no_AEW)
Aeq=sparse(length(cover_pts),length(index_cop));
temp_Aeq=sparse(length(cover_pts),length(index_dmd_pts));

k=1;
for i=1:length(cover_pts)
    for j=1:length(index_dmd_pts)
        if index_dmd_pts(j)==cover_pts(i)
            in_dmd(k)=j;
            k=k+1;
        end
    end
end

j=1;
for i=1:length(cover_pts)
    temp_Aeq(i,in_dmd(j))=1;
    j=j+1;
end

Aeq=horzcat(Aeq,temp_Aeq);
beq=ones(length(cover_pts),1);
beq=sparse(beq);

open('only_grids_east_dmd_pts.fig')
```

```
 for i=1:length(cover_pts)
    geoshow(dmd_pts(cover_pts(i),1),dmd_pts(cover_pts(i),2),...
    'DisplayType','point','markeredgecolor','b','markerfacecolor',...
    'b','marker','o')
end

n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
    if dmd_pts(i,3)~=0
       f(1,i+length(turkiye_points))=dmd_pts(i,4);
    end
end
[east_dmd_pts,east_cop,f_new,A_new,b_new,index,index_dmd_pts,...
                        index_cop]=eastern_sc(risk,dmd_pts,cop,A,f,4);
for i=1:length(east_cop)
    if east_cop(i,4)~=0
       geoshow(east_cop(i,1),east_cop(i,2),'DisplayType',...
       'point','markeredgecolor','k','markerfacecolor','k','marker','d')
    end
end

time1=cputime;
x=bintprog(f_new,A_new,b_new,Aeq,beq);
time2=cputime;
time=time2-time1;
solution=find(x);
for i=1:no_AEW
real_sol(i)=index(solution(i));
end
```

```
 for i=1:no_AEW
     sol(i,1)=cop(real_sol(i),1);
     sol(i,2)=cop(real_sol(i),2);
end
show_on_the_map(sol,'sol',1,1,185)
COPs=real_sol;
Covered_Demand_Points=solution-no_AEW;
Coverage_Rate=(solution-4)/1170*100;
end
%%%%%%%%%%%%% END OF EAST RELOCATION %%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%% WHOLE SCENARIO %%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [dmd_pts,cop,f_new,A_new,b_new,index,index_dmd_pts,...
                    index_cop]=whole_sc(risk,dmd_pts,cop,A,f,no_AEW)
for i=1:length(cop)
    if cop(i,4)<(1-risk)
      cop(i,4)=0;
    end
end
[f_new,A_new,b_new,index,index_dmd_pts,index_cop]=...
                      mtrx_changes(cop,dmd_pts,f,A,no_AEW);
end
%%%%%%%%%%%%% END OF WHOLE SCENARIO %%% %%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%% RUN WHOLE SCENARIO %%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [real_sol,percent,covered_dmd_pts]=run_whole_sc...
```

```
                                        (cop,turkiye_points,dmd_pts,risk,A,no_AEW)
open('only_grids_whole_dmd_pts.fig')
for i=1:length(dmd_pts)
   if dmd_pts(i,3)~=0
      dmd_pts(i,4)=-100;
   end
end
n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
   if dmd_pts(i,3)~=0
      f(1,i+length(turkiye_points))=dmd_pts(i,4);
   end
end
[dmd_pts,cop,f_new,A_new,b_new,index,index_dmd_pts,...
                              index_cop]=whole_sc(risk,dmd_pts,cop,A,f,no_AEW);
for i=1:length(cop)
   if op(i,4)~=0
      geoshow(cop(i,1),cop(i,2),'DisplayType',...
      'point','markeredgecolor','k','markerfacecolor','k','marker','d')
   end
end
[real_sol]=solve_MCLP(f_new,A_new,b_new,index,no_AEW,cop);
x=bintprog(f_new,A_new,b_new);
o=length(find(x));
covered_dmd_pts=o-no_AEW;
percent=(o-4)/2303*100;
end
%%%%%%%%%%%% END OF RUN WHOLE SCENARIO %%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%% WHOLE RELOCATION %%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [time,Covered_Demand_Points,Coverage_Rate,COPs]=...
  whole_relocate(turkiye_points,cop,dmd_pts,cover_pts,index_dmd_pts,...
  index_cop,f,A,no_AEW)
Aeq=sparse(length(cover_pts),length(index_cop));
temp_Aeq=sparse(length(cover_pts),length(index_dmd_pts));

k=1;
for i=1:length(cover_pts)
    for j=1:length(index_dmd_pts)
        if index_dmd_pts(j)==cover_pts(i)
            in_dmd(k)=j;
            k=k+1;
        end
    end
end

j=1;
for i=1:length(cover_pts)
    temp_Aeq(i,in_dmd(j))=1;
    j=j+1;
end

Aeq=horzcat(Aeq,temp_Aeq);
beq=ones(length(cover_pts),1);
beq=sparse(beq);

open('only_grids_whole_dmd_pts.fig')
```

```
for i=1:length(cover_pts)
    geoshow(dmd_pts(cover_pts(i),1),dmd_pts(cover_pts(i),2),'DisplayType',...
    'point','markeredgecolor','b','markerfacecolor','b','marker','o')
end

n=length(turkiye_points)+length(dmd_pts);
f=sparse(1,n);
for i=1:length(dmd_pts)
    if dmd_pts(i,3)~=0
       f(1,i+length(turkiye_points))=dmd_pts(i,4);
    end
end
[dmd_pts,cop,f_new,A_new,b_new,index,index_dmd_pts,...
                        index_cop]=whole_sc(0.3,dmd_pts,cop,A,f,no_AEW);
for i=1:length(cop)
    if cop(i,4)~=0
       geoshow(cop(i,1),cop(i,2),'DisplayType',...
       'point','markeredgecolor','k','markerfacecolor','k','marker','d')
    end
end

time1=cputime;
x=bintprog(f_new,A_new,b_new,Aeq,beq);
time2=cputime;
time=time2-time1
solution=find(x);
for i=1:no_AEW
real_sol(i)=index(solution(i));
end
```

```
for i=1:no_AEW
    sol(i,1)=cop(real_sol(i),1);
    sol(i,2)=cop(real_sol(i),2);
end
show_on_the_map(sol,'sol',1,1,185)
COPs=real_sol;
o=length(find(x));
Covered_Demand_Points=o-no_AEW;
Coverage_Rate=(o-4)/2303*100;
end
%%%%%%%%%%%% END OF WHOLE RELOCATION %%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%% MEASURE MIN COVER DISTANCE %%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [dfrn,mindst1,mindst2]=dst_msr1(cop1_frst,cop2_frst,cop1_scnd,...
                                    cop2_scnd,border,cop)
radii=nm2deg(185);
[intlat1 intlon1]=crossfix([cop(cop1_frst,1) cop(cop2_frst,1)]',...
                              [cop(cop1_frst,2) cop(cop2_frst,2)]',[radii radii]',[0 0]');
for i=1:length(border)
   dst1(i)=deg2nm(distance('rh',border(i,1),border(i,2),intlat1(1),.intlon1(1)));
end
mindst1=min(dst1);
[intlat2 intlon2]=crossfix([cop(cop1_scnd,1) cop(cop2_scnd,1)]',...
                              [cop(cop1_scnd,2) cop(cop2_scnd,2)]',[radii radii]',[0 0]');
for i=1:length(border)
   dst2(i)=deg2nm(distance('rh',border(i,1),border(i,2),intlat2(1),intlon2(1)));
end
```

```
mindst2=min(dst2);
dfrn=mindst2-mindst1;
end
%%%%%%%%%% END OF MEASURE MIN COVER DISTANCE %%%%%%%%%%%
```

Appendix C: Blue Dart Submission Form

Blue Dart Submission Form

First Name: Nebi Last Name: SARIKAYA

Rank (Military, AD, etc.): 1St Lt. Designator # AFIT/GOR/ENS/09-14M

Student's Involved in Research for Blue Dart: 1St Lt. Nebi SARIKAYA

Position/Title: Turkish Officer / Master's Student

Phone Number: E-mail: nebi.sarikaya.tr@afit.edu

School/Organization: AFIT/ENS

Status: [X] Student [ ] Faculty [ ] Staff [ ] Other

Optimal Media Outlet (optional): ______________________________________

Optimal Time of Publication (optional): ________________________________

General Category / Classification:

[ ] core values	[ ] command	[ ] strategy
[ ] war on terror	[ ] culture & language	[ ] leadership & ethics
[ ] warfighting	[ ] international security	[ ] doctrine

[X] other (specify): Air Defense

Suggested Headline: Determining the Orbit Locations of Turkish Airborne Early

Warning and Control Aircraft over the Turkish Air Space

Keywords: Air defense, Airborne Early Warning and Control (AEW&C) Aircraft, Integer Programming, MCLP, Location, Optimization.

Blue Dart

The technology improvement affects the military needs of individual countries. The new doctrine of defense for many countries emphasizes detecting threats as far away as you can from your homeland. Today, the military uses both ground RADAR and Airborne Early Warning and Control (AEW&C) Aircraft. AEW&C aircraft has become vital to detect low altitude threats that a ground RADAR cannot detect because of obstacles on the earth. Turkey has ordered four AEW&C aircraft for her air defense system because of the lack of complete coverage by ground RADAR.

This research provides optimal orbit locations that can be updated according to the threats, for Turkish AEW&C aircraft in the combat arena. Three combat scenarios Turkey might encounter are examined. Turkey can expect threats from everywhere. The worst cases for these scenarios include bad weather conditions and in Electronic Counter Measure (ECM) environment, adversary Surface to Air Missile (SAM) sites which are located in areas unknown to Turkish intelligence and no Suppression of Enemy Air Defense (SEAD) aircraft which can eliminate the SAM sites using High Speed Anti-Radiation Missiles (HARM).

The concern is to cover and detect the threats as far as possible from Turkey within a risk that the commander accepts. The goal is to help decision makers decide how many AEW aircraft are needed to obtain full coverage.

In order to provide optimum results, a Maximal Coverage Location Problem technique is used and the model is coded in MATLAB® 2008a.

The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the US Government.

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Vita

First Lieutenant Nebi Sarıkaya was born in Istanbul, Türkiye. He graduated From Kuleli Military High School in Istanbul, in 1997. He entered the Turkish Air Force Academy in Istanbul an received the degree of Bachelor of Science in Computer Engineering in 2001. In the same year, he attended undergraduate pilot training course and became a pilot in 2003. He was assigned to 182nd Sparrow Hawk Squadron as an F-16 pilot in 2004 after F-16 training course. Having served three years in 182nd Squadron, he was chosen for Graduate School of Engineering, Air Force Institute of Technology. Upon graduation, he will be assigned to 8th Main Jet Base in Diyarbakır as an F-16 pilot.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This research provides optimal orbit locations that can be updated according to the threats, for Turkish AEW&C aircraft in the combat arena. Three combat scenarios Turkey might encounter are examined. Turkey can expect threats from everywhere. The worst cases for these scenarios include bad weather conditions and in Electronic Counter Measure (ECM) environment, adversary Surface to Air Missile (SAM) sites which are located in areas unknown to Turkish intelligence and no Suppression of Enemy Air Defense (SEAD) aircraft which can eliminate the SAM sites using High Speed Anti-Radiation Missiles (HARM).

The concern is to cover and detect the threats as far as possible from Turkey without entering the lethal range of adversary SAM sites and airfields. The goal is to help decision makers decide how many AEW aircraft are needed to obtain full coverage.

In order to provide optimum results, a Maximal Coverage Location Problem technique is used and the model is coded in MATLAB® 2008a.

15. SUBJECT TERMS

Air Defense, Airborne Early Warning & Control (AEW&C) Aircraft, MATLAB® Mapping Toolbox™, MATLAB® Optimization Toolbox™, Integer Programming, MCLP, Location, Optimization

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